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Vol. 246 **SEPTEMBER, 1948** **No. 3**

CONTENTS

Stabilization of Carrier-Frequency Servomechanisms. III. Methods of Obtaining Required Carrier Phase-Shift ..... ANDREW SOBCZYK 187

The Conestoga Wagon ..... THOMAS COULSON 215

Science in National Security ..... SCOTT B. RITCHIE 223

A Theory of the Internal Ballistics of the "Hoch-und-Niederdruck Kanone". J. CORNER 233

Notes from the National Bureau of Standards 249

The Franklin Institute Notes

Museum Notes 256

Library Notes 256

Notes from the Biochemical Research Foundation 266

Inhibitors for Ribonucleinase ..... CHARLES A. ZITTLE

Current Topics 214, 232, 269

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Vol. 246 SEPTEMBER, 1948 No. 3

STABILIZATION OF CARRIER-FREQUENCY SERVOMECHANISMS. III. METHODS OF OBTAINING REQUIRED CARRIER PHASE-SHIFT.*

BY

ANDREW SOBCZYK, Ph.D.[1]

ABSTRACT.

In a servomechanism using a two-phase alternating current control motor, a 90° difference is required in the phases of the carrier-frequency voltages applied to the fixed and control windings. This part describes and compares various methods of obtaining the phase difference.

The question of the possibility of a phase-shifting proportional-derivative parallel "T" is answered in the negative, by the result that in any parallel "T" transfer characteristic, if the quadratic factor in the numerator is of the proportional-derivative form at the correct resonant frequency, the amount of phase shift which may be obtained from the remaining portion of the transfer characteristic is less than arc tan $(2/n)$, where n is twice the carrier frequency divided by notch width. Thus for values of n high enough to have an appreciable stabilizing effect, the maximum obtainable intrinsic phase shift is negligible.

In order to obtain a large phase shift it is necessary to add either a series input or a load impedance to the parallel "T," or to use a phase-shifting network preceding or following the parallel "T." Formulae and design charts are given for determination of the values of the components of phase lag networks.

The method of calculation of tolerance requirements on the components, in terms of allowable deviation from the correct phase, is illustrated by an example of a phase lag network used in conjunction with a bridge "T" proportional-derivative network.

1. INTRODUCTION.

As mentioned in Part I, it is necessary that the phase of the carrier of the modulated error signal applied to the control winding of the two-phase motor differ by 90° from the phase of the voltage on the fixed winding. Actually in the servo controller a phase shift different from

* This paper is a continuation of Parts I and II, published in the JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 246, July, p. 21, and August, p. 95 (1948).

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90° is usually required, in order to compensate for phase shift which occurs in the selsyns or elsewhere in the servo circuit.

All methods of obtaining phase shift of the carrier cause the frequency characteristic of the a-c. servo controller to become unsymmetrical about the carrier frequency, and also affect the phase characteristic. This distortion of the frequency-phase characteristics, and the question of its effect on servo performance, would not arise in a case where it was feasible to shift, instead, the phase of the voltage applied to the fixed winding. (Assuming the simplified motor, the effect of the distortion on stability and error in any case may be determined by the method of Part I.)

So far as obtaining the proportional-derivative effect on the modulation is concerned, the essential portion of the transfer characteristic of the parallel "T" is the factor $\left[1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right]$ in the numerator. Accordingly, in the following first section we investigate the phase shift which can be obtained from the remaining portion of the parallel "T" transfer characteristic, preserving the proportional-derivative factor in the numerator.

2. PHASE SHIFT AT ω_0 IN TERMS OF INDEPENDENT CONSTANTS IN THE PARALLEL "T."

Let the numerator and denominator of the parallel "T" transfer characteristic

$$\frac{E_2}{E_1} = \frac{T_1T_2T_3p^3 + T_1(S_2 + T_3)p^2 + (T_1 + S_1)p + 1}{T_1T_2T_3p^3 + [T_1(S_2 + T_3) + T_2(T_1 + S_1 + T_3)]p^2 + (T_1 + S_1 + T_2 + T_3)p + 1}$$

be multiplied by $n\omega_0/2p$, and let $p = j\omega$. Then in order that the numerator consist of the proportional-derivative characteristic

$$\left[1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right],$$

multiplied by a linear factor $(Uj\omega + 1)$, the following conditions must be satisfied by the fundamental time constants:

$$T_1T_2T_3 = \frac{u}{\omega_0^3}, \tag{1}$$

$$T_1(S_2 + T_3) = \frac{1}{\omega_0^2}\left(1 + \frac{2u}{n} \right), \tag{2}$$

$$T_1 + S_1 = \frac{1}{\omega_0}\left(\frac{2}{n} + u \right). \tag{3}$$

Suppose that these conditions are satisfied. Then we may consider T_1 and T_2 as independent variables, T_3, S_1, and S_2 as dependent variables: $T_3 = u/\omega_0^3 T_1 T_2$ from Eq. 1, and then S_2 and S_1 may be expressed in terms of T_1, T_2 from Eqs. 2 and 3. For positive S_1 and S_2, we see that T_1, T_2 must be restricted to lie in the region $T_2\omega_0 > nu/(n + 2u)$, $T_1\omega_0 < (2 + nu)/n$.

In terms of $T_1\omega_0$, $T_2\omega_0$, u, the phase shift ϕ at ω_0 is given by:

$$\tan \phi = \frac{u^2 - z}{(u^2 + 1)\left[a + \frac{n}{2}(1 + z) \right] + u(1 + z)}, \tag{4}$$

where $a = T_1\omega_0$, $z = T_1 T_2 \omega_0^2$, $n = T_d\omega_0$. Thus if $T_1 T_2 \omega_0^2 < u^2$, the phase shift is a lead; and if $T_1 T_2 \omega_0^2 > u^2$, it is a lag. If $T_1 T_2 \omega_0^2 = u^2$, then not only is there zero phase shift at ω_0, but also it may be verified that the factor $(Up + 1)$ of the numerator is also a factor of the denominator, so that the transfer characteristic is of the form

$$\frac{E_2}{E_1} = \frac{(Up + 1)\left(\frac{1}{\omega_0^2} p^2 + \frac{2}{n\omega_0} p + 1 \right)}{(Up + 1)\left(\frac{1}{\omega_0^2} p^2 + \frac{2}{m\omega_0} p + 1 \right)} = \frac{m}{n} \frac{\left[1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right]}{\left[1 + j \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right]}.$$

The gain at ω_0 is given by:

$$g = \frac{2a(u^2 + 1)^{\frac{1}{2}}}{[(2a + nz + n + 2u)^2 + (2au + nu + 2z + znu)^2]^{\frac{1}{2}}}$$

$$= \frac{2a}{2(a + u) + n(1 + u^2)} \quad \text{in case } z = u^2.$$

Let us examine Eq. 4 for $\tan \phi$ to determine the maximum amount of phase shift which can be obtained. The expression:

$$\frac{u^2 - z}{K(u^2 + 1) + u(1 + z)}$$

is a monotonic function of u; its value increases from $-z/K$ at $u = 0$ to $1/K$ as $u \to \infty$. Therefore the tangent of the angle of phase lead cannot be greater than $\dfrac{1}{a + n(1 + z)/2} < \dfrac{2}{n}$. The tangent of the angle of phase lag cannot be greater than

$$\frac{z}{\left[a + \frac{n}{2}(1 + z) \right]} = \frac{1}{\left[\frac{a}{z} + \frac{n}{2}\left(\frac{1}{z} + 1 \right) \right]} < \frac{2}{n}.$$

Thus for $T_d\omega_0 = n = 15$, the upper bound of possible phase shift is less than 7.6°. Actually, the bounds as found by calculation, for the case of equal condensers, were 3.8° lag, 0.5° lead.

It may be verified that Eqs. 1, 2, and 3 are invariant when the input and output of the parallel "T" are reversed, that is, when $R_2 \rightleftarrows R_3$ and $C_1 \rightleftarrows C_3$. They are also invariant when one of the individual "T"'s of the two "T"'s in parallel is reversed, that is, when either $R_2 \rightleftarrows R_3$, or $C_1 \rightleftarrows C_3$. Thus any proportional-derivative parallel "T" is reversible, without changing T_d, and the individual "T"'s likewise are reversible, to within the practically negligible amount of phase shift of the carrier.

3. LOAD IMPEDANCE AND SERIES INPUT IMPEDANCE.

Though the intrinsic phase shift obtainable in the parallel "T," together with the proper proportional-derivative characteristic for usably high values of T_d, is very small, an appreciable phase shift at the carrier frequency may be obtained (1) by loading the output of the parallel "T," or (2) by inserting a resistor or other impedance in series

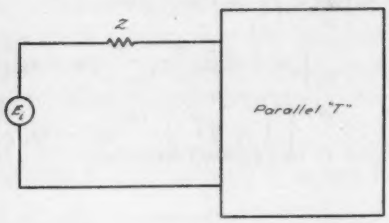

FIG. 1.

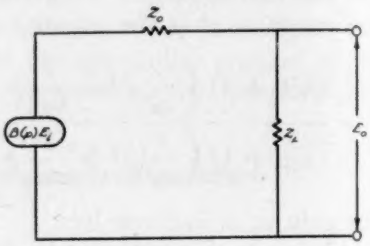

FIG. 2.

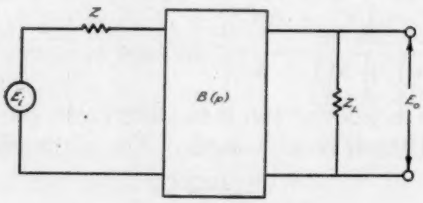

FIG. 3.

with the input to the parallel "T." A third method is to insert a one- or two-stage *R-C* or *C-R* phase-lag or phase-lead network either preceding or following the proportional-derivative parallel "T." (With any of the three methods, there is of course an accompanying effect on the gain-phase margin diagram, which may be calculated as in Part I.)

In this section we consider (1) and (2). If the input impedance to the parallel "T" is $A - jB$, and the source of E_i has series impedance Z, Fig. 1, the phase shift is $\angle [(A - jB)/(A + Z - jB)]$. Thus if Z is resistive, the phase shift approaches a lag of arc tan B/A as $Z \rightarrow \infty$; and if Z is inductive, a phase lag up to $90° +$ arc tan B/A may be obtained.

FIG. 5.

FIG. 4.

$$\text{Output Impedance } Z_o = \frac{6.9 + 32.2\left(\frac{\omega}{\omega_0}\right)^2 - 5.82\left(\frac{\omega}{\omega_0}\right)^4}{1 + 2.9\left(\frac{\omega}{\omega_0}\right)^2 + 56.4\left(\frac{\omega}{\omega_0}\right)^4 + 0.422\left(\frac{\omega}{\omega_0}\right)^6} \times 10^{-3}$$

$$+ j\frac{- 31.6\left(\frac{\omega}{\omega_0}\right) - 11.1\left(\frac{\omega}{\omega_0}\right)^3 - 2.66\left(\frac{\omega}{\omega_0}\right)^5}{1 + 2.9\left(\frac{\omega}{\omega_0}\right)^2 + 56.4\left(\frac{\omega}{\omega_0}\right)^4 + 0.422\left(\frac{\omega}{\omega_0}\right)^6} \times 10^{-3}.$$

Notch width = 8 cps. ($T_d\omega_0 = 15$)
60 cps. Parallel "T"
$Z_o = 0.001285 + (-0.001282)$ at 60 cps.
$Z_o = 0.00182$ megohms
In case $C_1 = C_2 = C_3 = 1$ μfd., load resistor $R_4 = \infty$, 0.00182, 0.00514.

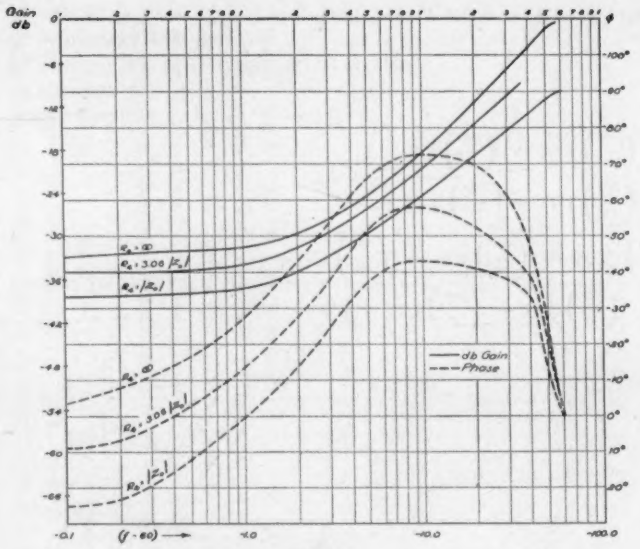

FIG. 6.

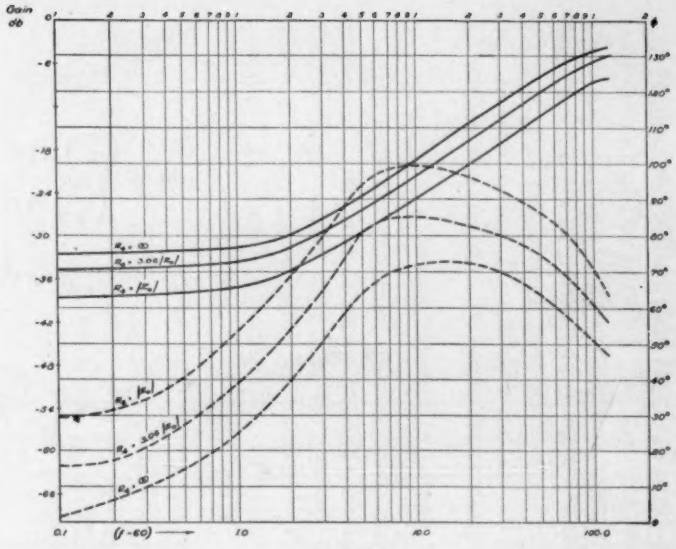

FIG. 7.

$$\text{Output Impedance } Z_o = \frac{7.19 + 25.4\left(\frac{\omega}{\omega_0}\right)^2 + 7.30\left(\frac{\omega}{\omega_0}\right)^4}{1 + 1.47\left(\frac{\omega}{\omega_0}\right)^2 + 84.7\left(\frac{\omega}{\omega_0}\right)^4 + 0.0486\left(\frac{\omega}{\omega_0}\right)^6} \times 10^{-3}$$

$$+ j\,\frac{-24.7\left(\frac{\omega}{\omega_0}\right) - 63.4\left(\frac{\omega}{\omega_0}\right)^3 - 266\left(\frac{\omega}{\omega_0}\right)^5}{1 + 1.47\left(\frac{\omega}{\omega_0}\right)^2 + 84.7\left(\frac{\omega}{\omega_0}\right)^4 + 0.0476\left(\frac{\omega}{\omega_0}\right)^6} \times 10^{-3}.$$

Notch width = 4 cps. ($T_d\omega_0 = 30$)
60 cps. Parallel "T"
$Z_o = 0.00128 + (-0.001502)$ at 60 cps.
$Z_o = 0.00197$ megohms
In case $C_1 = C_2 = C_3 = 1$ μfd., load resistor $R_4 = \infty$, 0.00197, 0.00602.

If a load impedance Z_L is connected to the output of the parallel "T," by Thevenin's theorem the circuit is equivalent to Fig. 2, where $B(p)$ is the parallel "T" transfer characteristic. If the output impedance is $Z_o = C - jD$, the phase shift is $Z_L/(C - jD + Z_L)$. Thus if Z_L is resistive, the phase shift approaches a lead of arc tan D/C as $Z_L \to 0$; and if $\angle Z_L = \theta > 0$, a phase lead up to θ + arc tan D/C may be obtained by taking Z_L to be sufficiently small.

Since the gain of the transfer characteristic is small, the effects of series input impedance and load impedance are nearly independent, and the total phase shift with both is approximately equal to the sum of the phase shifts which would be caused by each separately. Thus for example if Z is a large resistance, and Z_L a large capacity, a total phase lag of approximately $\angle Z_i + (90° - \angle Z_o)$ may be obtained.

If series input impedance Z and load impedance Z_L are connected to a transfer characteristic $B(p)$, Fig. 3, it may be shown that the resulting transfer characteristic is:

$$\frac{E_o}{E_i} = \frac{B(p)}{\left(1 + \frac{Z}{Z_i}\right)\left(1 + \frac{z_{22}}{Z_L}\right) - \frac{Z_i}{Z_L}[B(p)]^2},$$

where $z_{22} = Z_o + Z_i[B(p)]^2$ is the output impedance with the input open-circuited.

Figures 4, 5, 6, and 7 show the effect of a load resistor on the parallel "T" transfer characteristic, for the case of equal condensers, with $T_d\omega_0 = 15$ and 30.

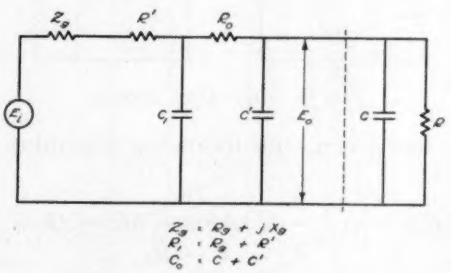

FIG. 8.

4. FORMULAE FOR PHASE-LAG NETWORKS.

Let the load on the phase-lag network at carrier frequency ω_0 be replaced by an equivalent resistor R and condenser C in parallel, as in Fig. 8. The capacity C is included in C_0; the source impedance Z_g, if purely resistive, is included in R_1. (A procedure for dealing with the case where Z_g is complex is indicated later.) The transfer character-

istic is:

$$\frac{E_o}{E_i} = \frac{R}{RT_1T_0p^2 + [R_0T_1 + R(T_0 + S_1 + T_1)]p + R + R_0 + R_1},$$

where $T_0 = R_0C_0$, $T_1 = R_1C_1$. Thus the angle of phase *lag* through the network is:

$$\phi = \arctan \frac{\omega_0[R(R_0 + R_1)C_0 + T_1(R_0 + R)]}{R + R_0 + R_1 - RT_0T_1\omega_0^2}.$$

Let $\tan \phi = -k$. Then the gain is:

$$g = \frac{R}{\pm (RT_0T_1\omega_0^2 - R - R_0 - R_1)(1 + k^2)^{\frac{1}{2}}},$$

where the plus sign corresponds to $\phi > 90°$, the minus sign to $\phi < 90°$.

Suppose that k, R, C_0, C_1 are given. Then the following formulae determine R_0, R_1 for maximum gain.

$$c(1 - kb)mR_0^2 + [b(m + 1) + c(n + mr - kbn) + k(1 + m)]R_0 + n(b + cR) + k(R + n) = 0,$$

$$R_1 = mR_0 + n,$$

where

$$b = \omega_0RC_0, \quad c = C_1\omega_0, \quad m = (b^2 + 1)/[(b^2 + 1) + bcR], \quad n = R/[(b^2 + 1) + bcR].$$

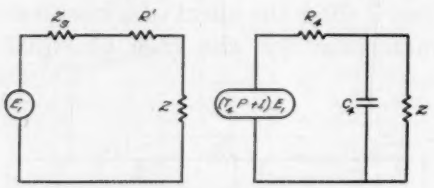

FIG. 9. Equivalent circuits.

If k, R, C_0, C_1 are given, the following formulae determine R_0, R_1 for a specified gain g:

$$c(1 - kb)R_0^2 - c(1 - kb)AR_0 - kR - (k + b)A = 0,$$

$$R_1 = A - R_0,$$

where $A = R[(kb - 1)g^{-1}(1 + k^2)^{-\frac{1}{2}} + kb - 1 - k]/(b + k + 1 - kb)$.

In case Z_g is complex, let $Z_g + R' = x + jy$. Then the voltage source E_1 with impedance $x + jy$, at frequency ω, is equivalent to a source $(T_4p + 1)E_1$ with resistance R_4, paralleled by a (positive or negative) capacity C_4, where $x = R_4/(1 + T_4^2\omega^2)$, $y = -R_4T_4\omega/(1 + T_4^2\omega^2)$, $T_4 = R_4C_4$, or $R_4 = x + y^2/x$, $T_4\omega = -y/x$. (See Fig. 9.) Thus to compute the phase shift, R_4 may be substituted for R_1, and C_1 modified by the addition of C_4. Then the phase lag with respect to E_1 is $\phi -$ arc tan $T_4\omega_0$, and the gain is $g(1 + T_4^2\omega^2)^{\frac{1}{2}}$.

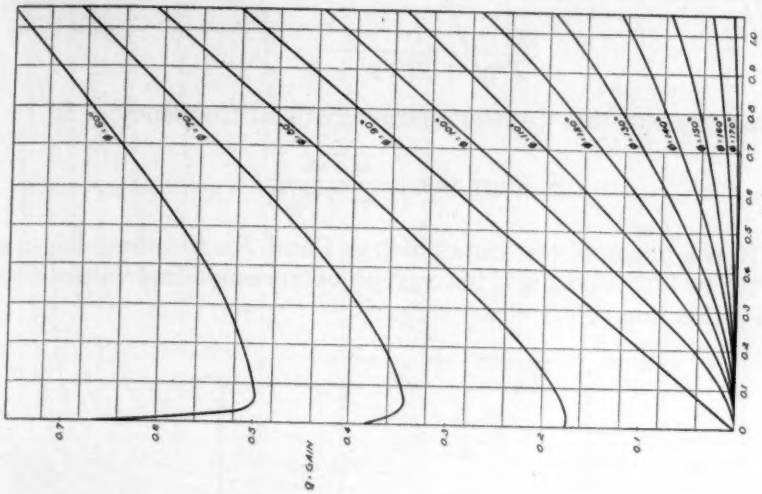

FIG. 11.

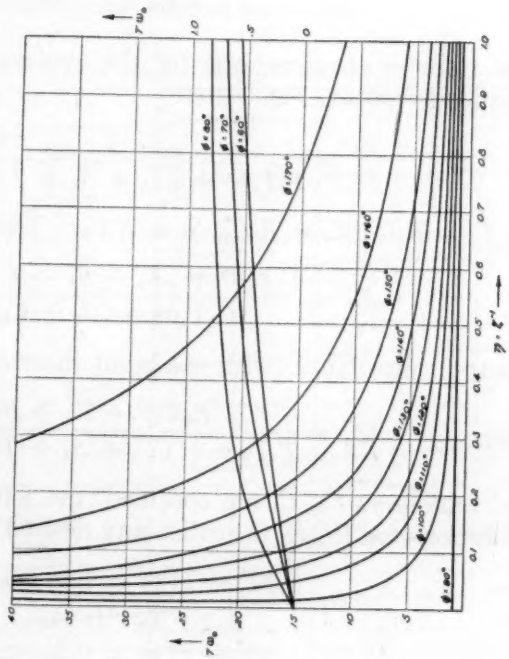

FIG. 10.

5. NUMERICAL VALUES FOR PHASE-LAG NETWORKS.

Consider the transfer characteristic

$$\frac{1}{T^2p^2 + 2\zeta Tp + 1}.$$

The phase lag ϕ of this transfer characteristic at frequency ω_0 is

$$\phi = \arctan \frac{2\zeta T\omega_0}{(1 - T^2\omega_0^2)}.$$

Figure 10 is a graph of the values of $\zeta \geqq 1$ and $T\omega_0$ for phase-lag angles ϕ from 60° to 170°, and Fig. 11 is a graph of corresponding values of gain at ω_0 as a function of $\zeta^{-1} = \eta$.

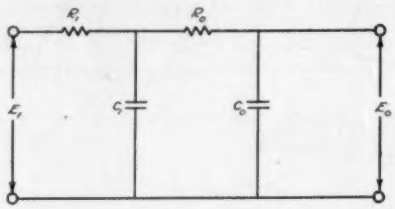

FIG. 12.

The transfer characteristic for the two-section phase-lag network with no load resistor, Fig. 12, is:

$$\frac{E_0}{E_1} = \frac{1}{T_1T_0p^2 + (T_0 + S_1 + T_1)p + 1},$$

where $T_1 = R_1C_1$, $T_0 = R_0C_0$, $S_1 = R_1C_0$. The input impedance is

$$Z_i = \frac{T_1T_0p^2 + (T_0 + S_1 + T_1)p + 1}{C_1T_0p^2 + (C_0 + C_1)p}.$$

The output impedance (with the input short-circuited) is

$$Z_o = \frac{R_0T_1p + R_0 + R_1}{T_1T_0p^2 + (T_0 + S_1 + T_1)p + 1}.$$

If the condensers C_0, C_1 are specified, the following formulae give the two solutions for R_0, R_1 to realize any desired ζ and T:

$$R_1 = \frac{\zeta T \pm T[\zeta^2 - 1 - (C_0/C_1)]^{\frac{1}{2}}}{(C_0 + C_1)},$$

$$R_0 = \frac{\zeta T \mp T[\zeta^2 - 1 - (C_0/C_1)]^{\frac{1}{2}}}{C_0}.$$

These solutions, for several sets of values for C_0, C_1, are the basis for the

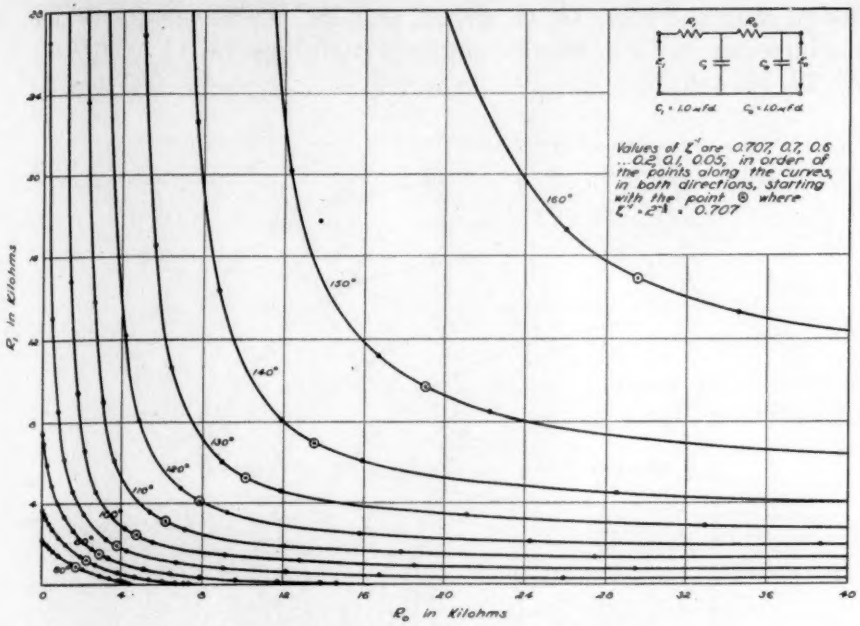
$C_1 = 1.0\ \mu fd.$ $C_0 = 1.0\ \mu fd.$
Values of ζ are 0.707, 0.7, 0.6 ... 0.2, 0.1, 0.05, in order of the points along the curves, in both directions, starting with the point ⊗ where $\zeta = 2^{-\frac{1}{2}} = 0.707$
160°
150°
140°
130°
120°
110°
100°
R_1 in Kilohms
R_0 in Kilohms

FIG. 13. Design chart for phase-lag networks.

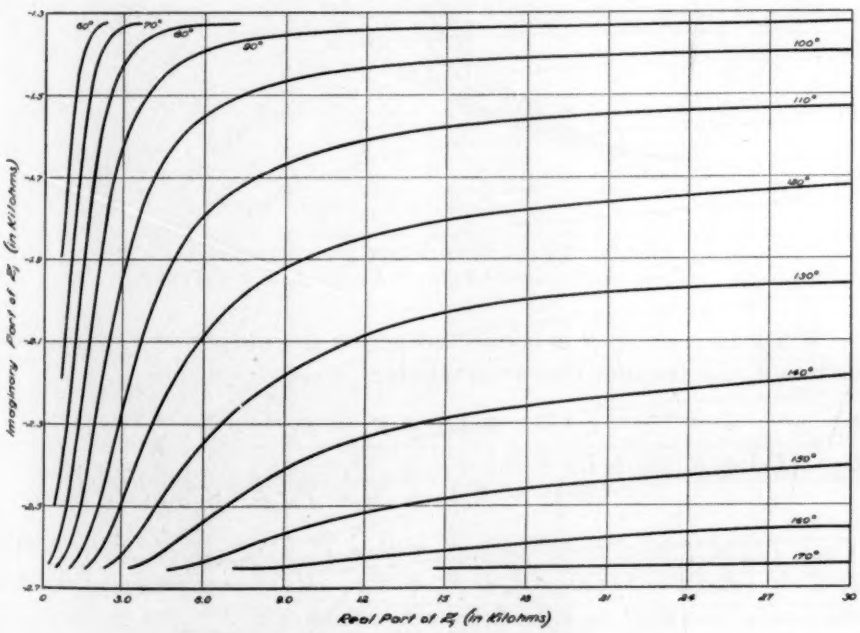

FIG. 14. Input impedances of phase-lag networks.
$C_1 = 1.0\ \mu fd.$, $C_0 = 1.0\ \mu fd.$, ζ, R_1, and R_0 as in Fig. 13.

design charts of Figs. 13, 16, 19, 22, and 25. Corresponding values of the impedances Z_i, Z_o may be obtained from Figs. 14, 15, 17, 18, 20, 21, 23, 24, 26, and 27.

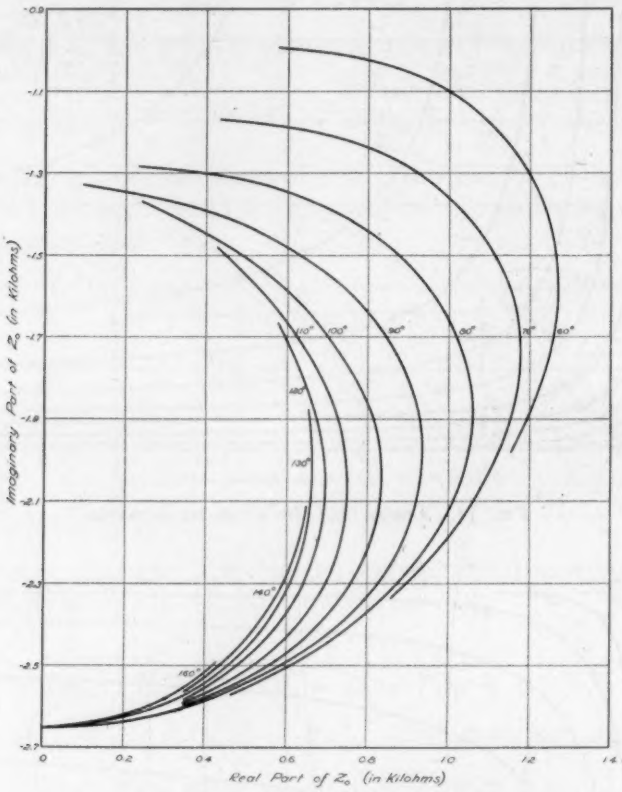

FIG. 15. Output impedances of phase-lag networks.
$C_1 = 1.0$ μfd., $C_0 = 1.0$ μfd., ζ, R_1, and R_0 as in Fig. 13.

If a load resistor R is connected across the output in Fig. 12, as in section 4, the transfer characteristic is:

$$\frac{E_0}{E_1} = \frac{R/(R + R_0 + R_1)}{T_1T_0p^2R/(R + R_0 + R_1) + [R_0T_1 + R(T_0 + S_1 + T_1)]p/(R + R_0 + R_1) + 1}.$$

Thus T and ζ become T' and ζ', where $T' = [R/(R + R_0 + R_1)]^{\frac{1}{2}}T$, $2\zeta'T' = [R_0T_1 + 2\zeta TR]/(R + R_0 + R_1)$. If T' and ζ' are calculated, the new phase shift may be determined from Fig. 10, and the new gain is $R/(R + R_0 + R_1)$ times the value corresponding to ζ' and T' in Fig. 11. Or, if the output impedance Z_o of the phase-lag network is at

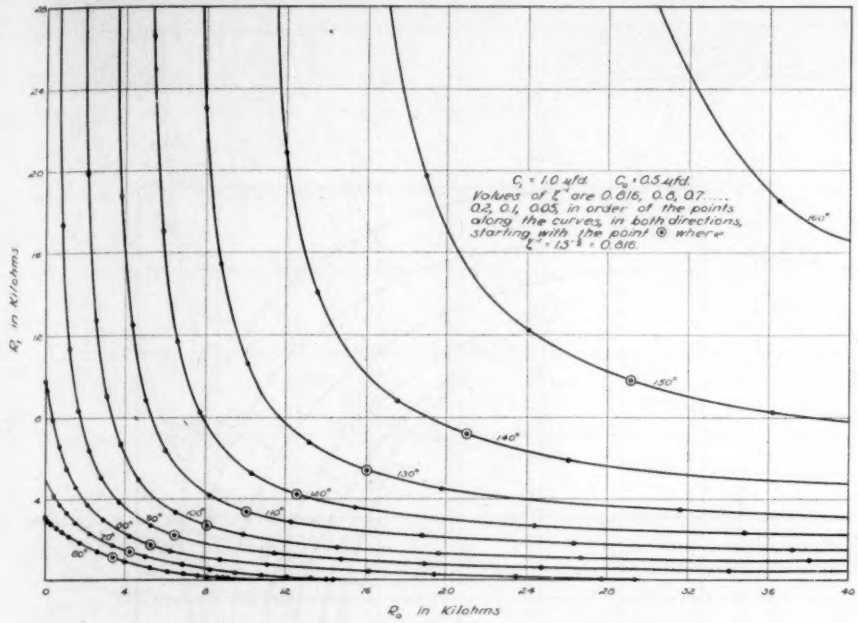

FIG. 16. Design chart for phase-lag networks.

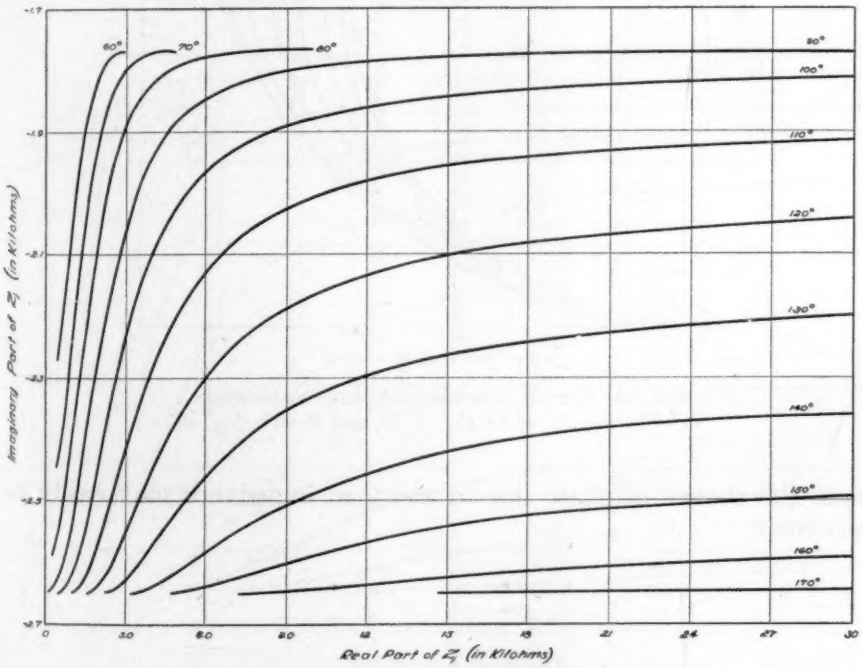

FIG. 17. Input impedances of phase-lag networks.
$C_1 = 1.0$ μfd., $C_0 = 0.5$ μfd., ζ, R_1, and R_0 as in Fig. 16.

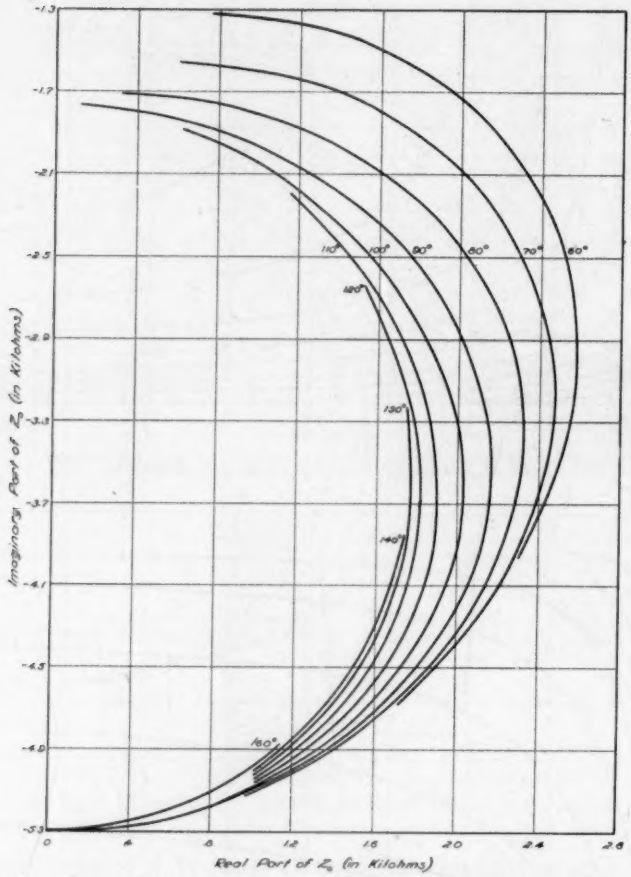

FIG. 18. Output impedances of phase-lag networks.
$C_1 = 1.0$ μfd., $C_0 = 0.5$ μfd., ζ, R_1, and R_0 as in Fig. 16.

hand, the change of phase due to any load impedance may easily be calculated.

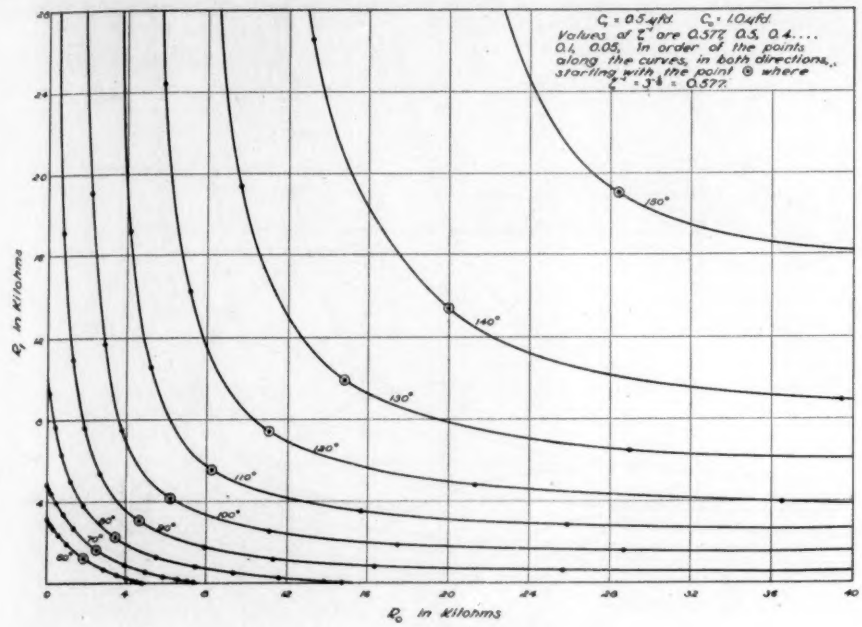

FIG. 19. Design chart for phase-lag networks.

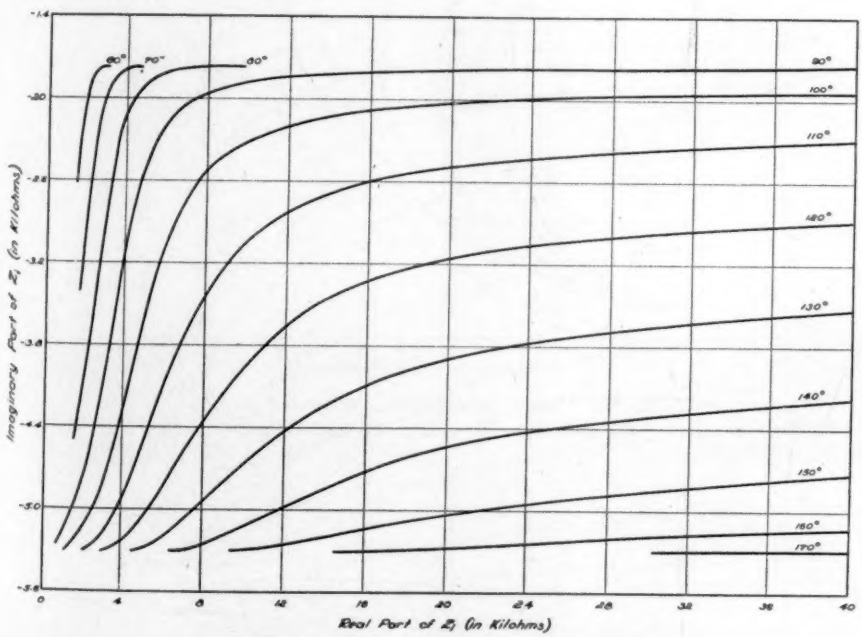

FIG. 20. Input impedances of phase-lag networks.
$C_1 = 0.5$ μfd., $C_0 = 1.0$ μfd., ζ, R_1, and R_0 as in Fig. 19.

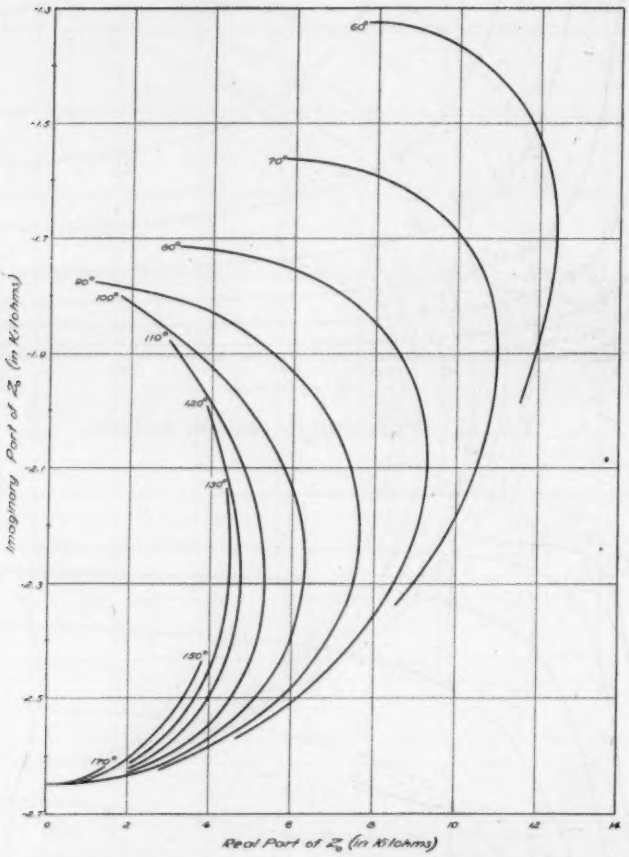

FIG. 21. Output impedances of phase-lag networks.
$C_1 = 0.5$ μfd., $C_0 = 1.0$ μfd., ζ, R_1, and R_0 as in Fig. 19.

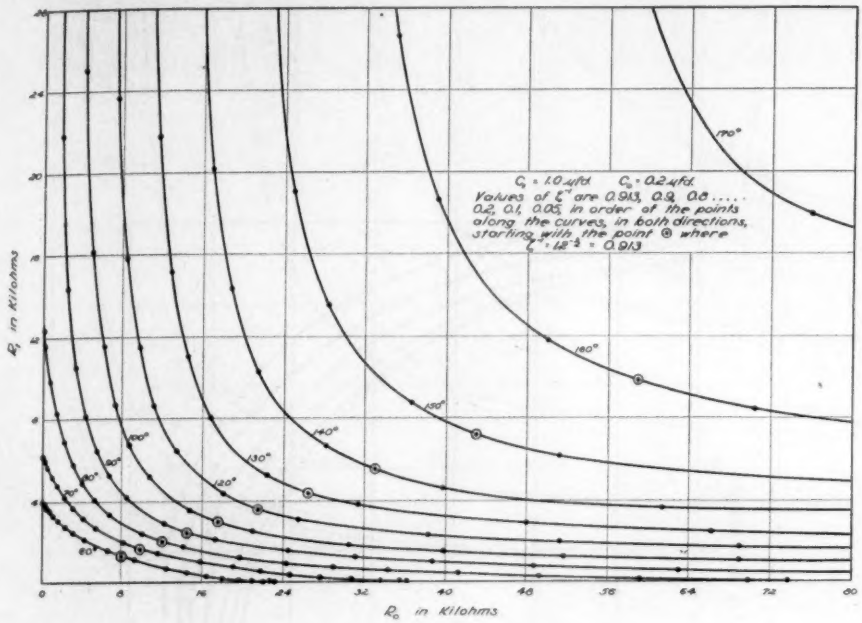

FIG. 22. Design chart for phase-lag networks.

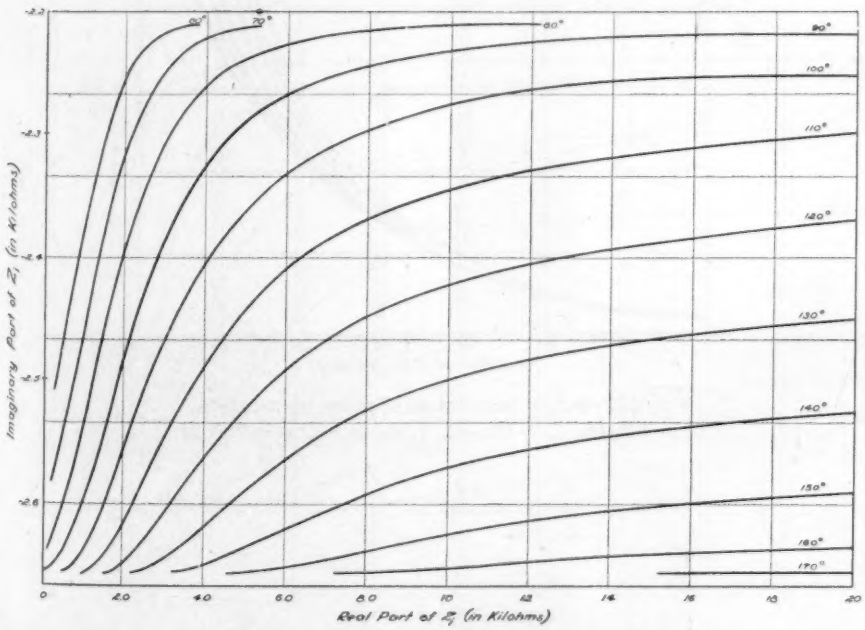

FIG. 23. Input impedances of phase-lag networks.
C_1 = 1.0 μfd., C_0 = 0.2 μfd., ζ, R_1, and R_0 as in Fig. 22.

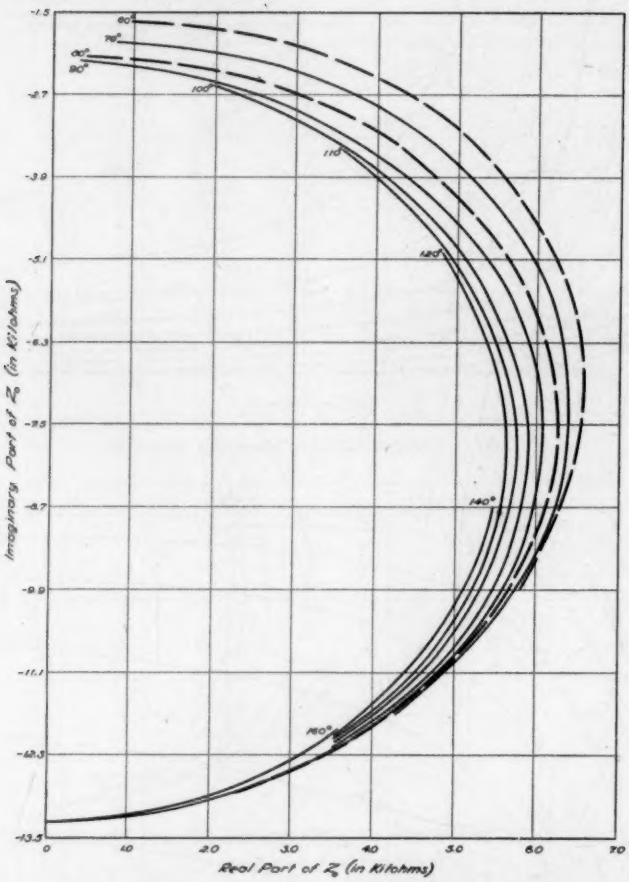

FIG. 24. Output impedances of phase-lag networks.
$C_1 = 1.0$ μfd., $C_0 = 0.2$ μfd., ζ, R_1, and R_0 as in Fig. 22.

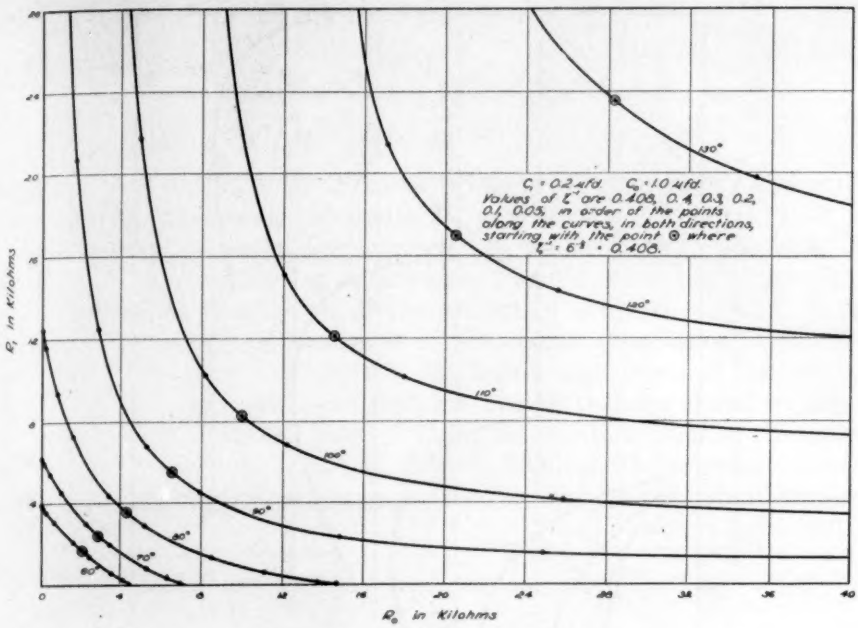
C_1 = 0.2 μfd. C_0 = 1.0 μfd.
Values of ζ' are 0.408, 0.4, 0.3, 0.2, 0.1, 0.05, in order of the points along the curves, in both directions, starting with the point ⊙ where $\zeta' = 6^{-\frac{1}{2}} = 0.408$.
130°
120°
110°
100°
90°
80°
70°
60°
R_1 in Kilohms
R_0 in Kilohms

FIG. 25. Design chart for phase-lag networks.

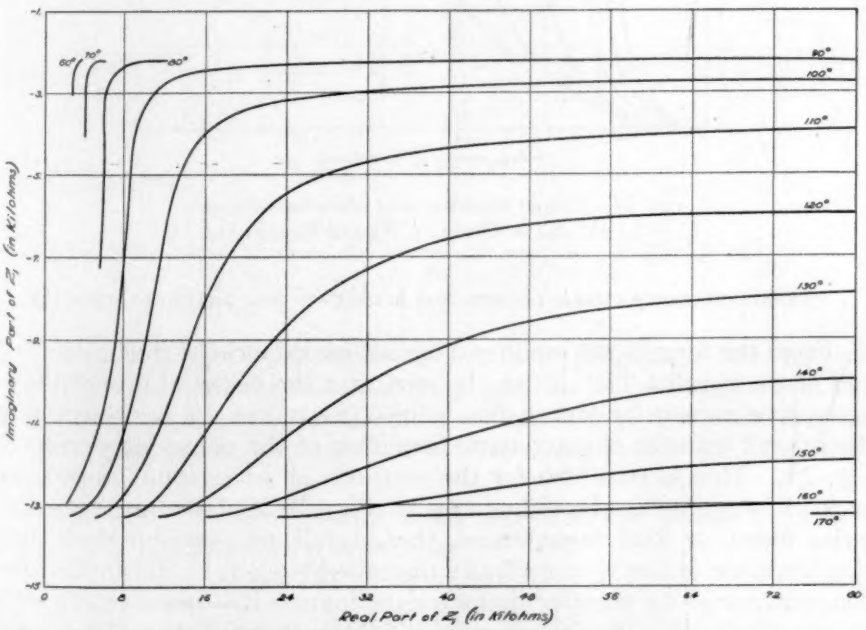

FIG. 26. Input impedances of phase-lag networks.
$C_1 = 0.2$ μfd., $C_0 = 1.0$ μfd., ζ', R_1, and R_0 as in Fig. 25.

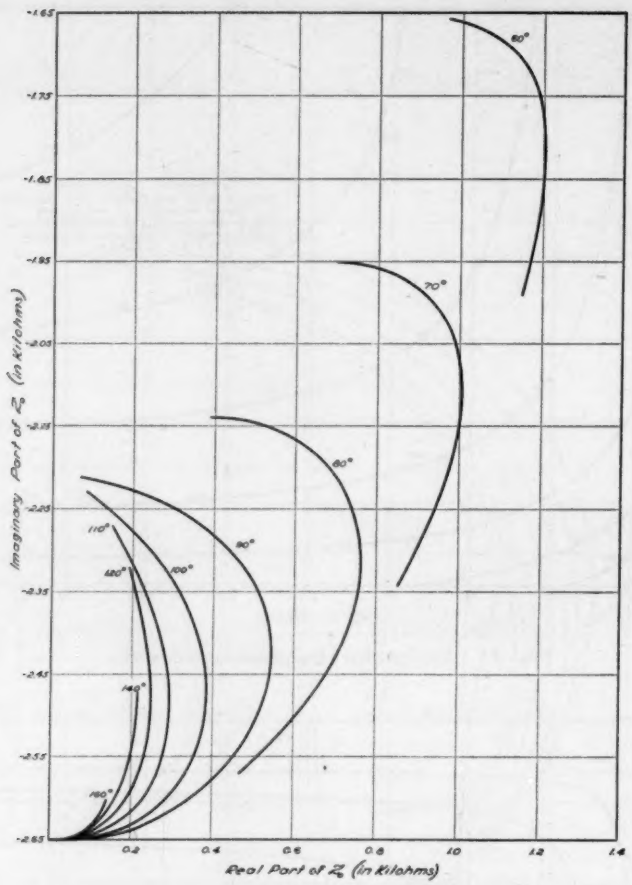

FIG. 27. Output impedances of phase-lag networks.
$C_1 = 0.2$ μfd., $C_0 = 1.0$ μfd., ζ, R_1, and R_0 as in Fig. 25.

6. OVERALL TRANSFER CHARACTERISTIC FOR BRIDGE "T" AND PHASE-LAG NETWORK.

From the form of the input and output impedances of the bridge "T" and of the parallel "T," it may be seen that the essential proportional-derivative numerator factor, $[\omega_0^{-2}p^2 + 2(n\omega_0)^{-1}p + 1]$, is preserved in the overall transfer characteristic for either of the phase-lag circuits of Fig. 28. This is true also for the methods of series input impedance or load impedance. In either case of Fig. 28, and for non-inductive series input or load impedances, the overall proportional-derivative characteristic is not very seriously disturbed since it is known that the denominator of the transfer characteristic for any R-C network can have no complex roots. For the parallel "T," the transfer characteristic for

either circuit of Fig. 28 will be of the form:

$$\frac{E_o}{E_i} = \frac{(U_3p + 1)\left(\frac{1}{\omega_0^2}p^2 + \frac{2}{n\omega_0}p + 1\right)}{(U_4p + 1)(U_1^2p^2 + 2\zeta_1U_1p + 1)(U_2^2p^2 + 2\zeta_2U_2p + 1)}, \quad (5)$$

where $\zeta_1 > 1$ and $\zeta_2 > 1$. For the bridge "T," the transfer characteristic will be of the same form with $U_3 = U_4 = 0$.

When two networks are connected in cascade, as for example the parallel "T" and phase-lag networks in Fig. 28, there will be no phase shift due to the connection of the output of the first network to the input of the second, if the angle of the output impedance of the first network is equal to the angle of the input impedance of the second. This of course does not mean that the overall transfer characteristic is the product of a constant gain $\leqq 1$ and the separate transfer characteristics for each network. In fact if $B(p)$, $B'(p)$ are the separate transfer characteristics for each of the two networks, Fig. 29, the overall transfer

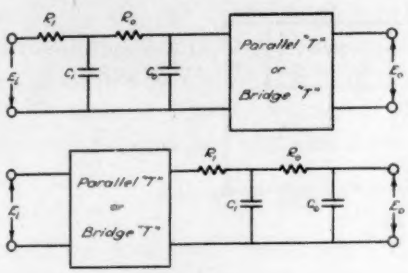

FIG. 28.

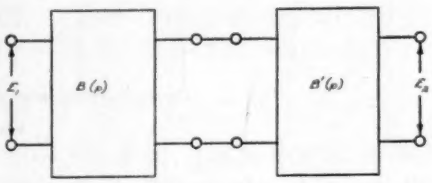

FIG. 29.

characteristic is:

$$\frac{E_2}{E_1} = \frac{B(p)B'(p)}{1 + \frac{z_{22}}{z_{11}'} - [B(p)]^2\frac{z_{11}}{z_{11}'}} = \frac{z_{11}'}{(z_{11}' + Z_o)}B(p)B'(p), \quad (6)$$

where z_{11}, z_{11}' are the separate input impedances, and $z_{22} = Z_o + z_{11}[B(p)]^2$ is the impedance looking into the output of the first network with the input open-circuited. This follows from the transfer characteristic of Fig. 3, where $Z = 0$; or immediately by Thevenin's theorem.

For the combination of phase-lag network and bridge "T" as in Fig. 30, the transfer characteristic is:

$$\frac{E_o}{E_i} = \frac{\frac{1}{\omega_0^2}p^2 + \frac{2}{n\omega_0}p + 1}{Ap^4 + Bp^3 + Cp^2 + Dp + 1}, \quad (7)$$

where

$$A = \frac{T_0T_1}{\omega_0^2} = \frac{T^2}{\omega_0^2}$$

$$B = \frac{(T_0 + S_1)}{\omega_0^2} + \frac{2T_1T_0}{m\omega_0} + \frac{T_1(R_0/R_2 + 1)}{\omega_0^2} = \frac{2\zeta T}{\omega_0^2} + \frac{2T^2}{m\omega_0} + \frac{T^2}{R_2C_0\omega_0^2},$$

$$C = \frac{2(T_0 + S_1 + T_1)}{m\omega_0} + \frac{(R_0/R_2 + 1)}{\omega_0^2} + \frac{R_1}{R_2\omega_0^2} + T_0T_1 + \frac{2T_1R_0/R_2}{n\omega_0}$$

$$= \frac{4\zeta T}{m\omega_0} + \frac{1}{\omega_0^2} + \frac{(2\zeta T - T_1)}{R_2C_0\omega_0^2} + T^2 + \frac{2T^2}{R_2C_0n\omega_0},$$

$$D = (T_0 + S_1 + T_1) + \frac{2(R_0 + R_1)/R_2}{n\omega_0} + \frac{2}{m\omega_0}$$

$$= 2\zeta T + \frac{2(2\zeta T - T_1)}{R_2C_0n\omega_0} + \frac{2}{m\omega_0}.$$

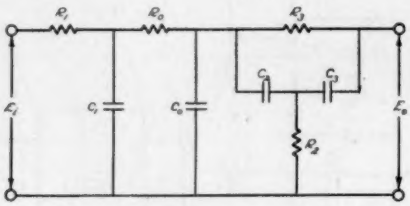

FIG. 30.

The transfer characteristic $B(p)$ of the phase-lag network is:

$$B(p) = \frac{1}{T^2p^2 + 2\zeta Tp + 1} = \frac{1}{T_1T_0p^2 + (T_0 + S_1 + T_1)p + 1},$$

where $T_1 = R_1C_1$, $T_0 = R_0C_0$, $S_1 = R_1C_0$. The transfer characteristic $B'(p)$ of the bridge "T" is:

$$B'(p) = \frac{\frac{1}{\omega_0^2}p^2 + \frac{2}{n\omega_0}p + 1}{\frac{1}{\omega_0^2}p^2 + \frac{2}{m\omega_0}p + 1} = \frac{T_2T_3p^2 + (T_2 + S_2)p + 1}{T_2T_3p^2 + (T_2 + S_2 + T_3)p + 1},$$

where $T_2 = R_2C_2$, $T_3 = R_3C_3$, $S_2 = R_2C_3$.

The transfer characteristic (7) is of the form (5) with $U_3 = U_4 = 0$. The denominator consists of a product of four linear factors:

$$(U_1^2p^2 + 2\zeta_1U_1p + 1)(U_2^2p^2 + 2\zeta_2U_2p + 1)$$
$$= \left(\frac{\mu_1}{\omega_0}p + 1\right)\left(\frac{\mu_2}{\omega_0}p + 1\right)\left(\frac{\mu_3}{\omega_0}p + 1\right)\left(\frac{\mu_0}{\omega_4}p + 1\right).$$

(The phase lag ϕ_i at ω_0 due to a linear factor $\left(\frac{\mu_i}{\omega_0}p + 1\right)$ is given by $\tan \phi_i = \mu_i$.) Since there are several combinations of products of pairs of the linear factors, U_1, ζ_1, U_2, ζ_2 of course are not unique for specified A, B, C, and D. The relations between U_1, U_2, ζ_1, ζ_2, and A, B, C, and D are:

$$\begin{aligned} A &= U_1^2 U_2^2, \\ B &= 2U_1U_2(\zeta_1 U_2 + \zeta_2 U_1), \\ C &= 4\zeta_1\zeta_2 U_1U_2 + U_1^2 + U_2^2, \\ D &= 2(\zeta_1 U_1 + \zeta_2 U_2). \end{aligned}$$

The procedure now will be indicated for answering the following two questions: (1) Given a bridge "T," and a phase-lag network either determined experimentally or designed by the method of a previous section to give the appropriate carrier phase shift, what are the values of U_1, ζ_1, U_2, ζ_2? (2) Given a bridge "T," what should be the values of the components of a phase-lag network in order to realize a specified set of values of U_1, U_2, ζ_1, ζ_2 or A, B, C, and D?

To answer (1), the values of A, B, C, and D may be calculated by the above formulae, and the roots for $x = (p/\omega_0)$ of the equation

$$A\omega_0^4 x^4 + B\omega_0^3 x^3 + C\omega_0^2 x^2 + D\omega_0 x + 1 = 0$$

found by numerical methods. Each of the four quantities μ_i in the factored form of the denominator then is given by $\mu_i = -1/x_i$, where x_i is one of the roots. The effect of the phase-lag network on stability of the bridge "T" servo then may be determined by referring to Fig. 32 in the next section.

To answer (2), we solve the second of the above sets of expressions for A, B, C, and D for T, ζ, $S_2 = R_2C_0$, $T_1 = R_1C_1$ in terms of A, B, C, and D. Since the bridge "T" is given, R_2 is known, and S_2 determines C_0. Formulae for the design of an unloaded phase lag network to realize any T, ζ have been given in section 4; from the formula for R_1, it follows that the ratio $r = C_0/C_1$ may be found from T_1 by solving the quadratic equation:

$$T_1^2 r^2 + (2T_1^2 - 2\zeta T T_1 + T^2)r + (T^2 - 2\zeta T T_1 + T_1^2) = 0.$$

The values of C_0 and r determine C_1; and R_0 is given by the formula of section 4 for R_0 in terms of ζ, T, r, and C_0. Thus if T, ζ, S_2, T_1 to realize a given set of A, B, C, and D are known, the phase-lag network components R_1, R_0, C_1, C_0 are determined.

The solutions for T, ζ, S_2, T_1 in terms of A, B, C, and D are as

follows:

$$T = \omega_0 A^{\frac{1}{2}},$$

$$\zeta \text{ is a root of } a\zeta^2 + b\zeta + c = 0,$$

where

$$a = \left[\frac{8T^2}{m\omega_0^2}\left(\frac{4}{m} - \frac{4}{n} - n\right)\right],$$

$$b = \left[\frac{4nTD''}{m\omega_0^2} + \frac{16TB'}{mn} + \frac{2TC''}{\omega_0}\left(\frac{4}{n} - \frac{8}{m} + n\right)\right],$$

$$c = \left[2(C'')^2 - \frac{n}{\omega_0}C''D'' - \frac{4\omega_0}{n}B'C''\right],$$

$$C'' = C - \frac{1}{\omega_0^2} - T^2, \quad D'' = D - \frac{2}{m\omega_0}, \quad B' = B - \frac{2T^2}{m\omega_0};$$

$$T_1 = 2\zeta T + \frac{2T^2D'\omega_0}{(nD' - 2C'\omega_0)},$$

$$S_2 = \frac{2T^2D'}{(2C'\omega_0 - nD')C'\omega_0} + \frac{2T^2}{nC'\omega_0},$$

where

$$C' = C'' - \frac{4\zeta T}{m\omega_0}, \qquad D' = D'' - 2\zeta T.$$

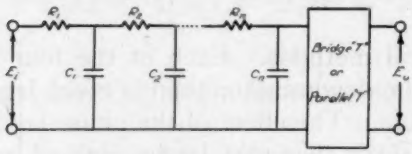

FIG. 31.

7. MULTI-SECTION PHASE-LAG NETWORKS. GAIN-PHASE MARGIN DIAGRAMS.

The transfer characteristic for an n-section R-C phase-lag network followed by a bridge "T," or for a bridge "T" followed by an n-section phase-lag network, is of the form:

$$\frac{E_o}{E_i} = \frac{\frac{1}{\omega_0^2}p^2 + \frac{2}{n\omega_0}p + 1}{(U_1p + 1)(U_2p + 1)\cdots(U_np + 1)(T_1p + 1)(T_2p + 1)}.$$

Excluding the proper proportional-derivative factor

$$(\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)(n\omega_0/2p),$$

the phase lag at any frequency ω of the remaining portion of the transfer characteristic is:

$$\phi = \Sigma \arctan U_i\omega + \arctan T_1\omega + \arctan T_2\omega - 90°.$$

Clearly, as $\omega \to \infty$, $\phi \to (n+1)90°$, so that for a phase lag ϕ_0 at ω_0, it is best to keep the number of sections n as small as possible, in order to minimize the change of phase with frequency in the vicinity of $\omega = \omega_0$. The frequency characteristic, on the other hand, is most flat, and the gain is largest, when the number of sections is large. For n R-C sections of equal time constant, as $n \to \infty$, the transfer characteristic $1/(Tp/n + 1)^n \to \exp(-Tp)$. Thus the limiting frequency characteristic is $|\exp(-j\omega T)| \equiv 1$ and the limiting phase lag is $\phi = \omega T$.

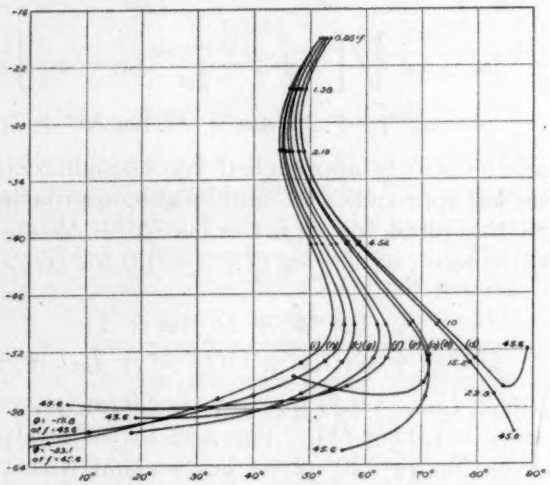

FIG. 32. Effect of phase-lag networks on gain-phase margin diagrams.

(*a*) Proportional-derivative parallel "T", $n = 15$, $m = 0.5$
(*b*) $G(j\omega) = 1 + jT_d \dfrac{(\omega + \omega_0)}{2\omega}(\omega - \omega_0) = B(j\omega)$, $T_d = 15/\omega_0$
} fixed phase 90° from carrier

(*c*) $G(j\omega) = B(j\omega)\exp(-j\omega U)$, $U = \pi/2\omega_0$
(*d*) $G(j\omega) = B(j\omega)/j\omega$
(*e*) $G(j\omega) = (\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)/(\omega_0^{-2}p^2 + 2\zeta\omega_0^{-1}p + 1)j\omega = C(p)/j\omega D(p)$, $n = 15$, $\zeta = 2.0$ (or $m = 0.5$)
(*f*) $\zeta = 2.0$, (*i*) $\zeta = 1.0$; $G(j\omega) = C(p)/(\omega_0^{-2}p^2 + 2\zeta\omega_0^{-1}p + 1)^2$
(*g*) $U_1\omega_0 = 2.68$, $U_2\omega_0 = 0.37$, $\zeta_1 = \zeta_2 = 2.0$,
(*h*) $U_1\omega_0 = 0.87$, $U_2\omega_0 = 1.73$, $\zeta_1 = \zeta_2 = 1.0$;

$$G(j\omega) = \frac{(\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)}{(U_1^2p^2 + 2\zeta_1U_1p + 1)(U_2^2p^2 + 2\zeta_2U_2p + 1)}$$

} fixed phase 0° from carrier applied to $G(j\omega)$

The gain-phase margin diagrams in Fig. 32, together with the M and E curves of Fig. 6, Part I, show the effect on error and stability of various methods of obtaining 90° phase lag, for a servo using the simplified motor with time constant $T = 0.2$ sec. Curve (*a*) is the decibel-phase margin plot for the proportional-derivative parallel "T" transfer characteristic $(\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)/(\omega_0^{-2}p^2 + 2\zeta\omega_0^{-1}p + 1)$, where $n = T_d\omega_0 = 15$, $\zeta = m^{-1} = 2.0$. (This is the same as curve (*d*) in Fig. 9, Part I.) Curve (*b*) is the decibel-phase margin plot for

$G(j\omega) = 1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0)$. (For curves (*a*) and (*b*) the fixed phase excitation is 90° out of phase with the carrier; for curves (*c*) through (*i*) the fixed phase excitation is in phase with the carrier applied to $G(j\omega)$.) Curve (*c*) is the plot for $G(j\omega) = \left[1 + jT_d \frac{\omega+\omega_0}{2\omega} (\omega-\omega_0)\right] e^{-j\omega U}$, where $U = \pi/2\omega_0$. This corresponds to a 90° phase-lag network having a very large number of sections and gain nearly 1. Curve (*d*) is the plot for $G(j\omega) = \left[1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right] \frac{1}{j\omega}$; curve (*e*) for

$$\left[1 + jT_d \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right] \Big/ \left[1 + jl \frac{\omega + \omega_0}{2\omega} (\omega - \omega_0) \right] j\omega$$
$$= (\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)/(\omega_0^{-2}p^2 + 2\zeta\omega_0^{-1}p + 1)j\omega.$$

The latter characteristic is approached by a single-section *R*-*C* network as its phase lag approaches 90° and its gain approaches 0. Curves (*f*) and (*i*) are the plots for $G(j\omega) = (\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)/(\omega_0^{-2}p^2 + 2\zeta\omega_0^{-1}p + 1)^2$, where $\zeta = 2.0$ for (*f*), $\zeta = 1.0$ for (*i*); and curves (*g*) and (*h*) for

$$G(j\omega) = \frac{(\omega_0^{-2}p^2 + 2p/n\omega_0 + 1)}{(U_1^2p^2 + 2\zeta_1U_1p + 1)(U_2^2p^2 + 2\zeta_2U_2p + 1)},$$

where $U_1\omega_0 = 2.682$, $U_2\omega_0 = 0.373$, $\zeta_1 = \zeta_2 = 2.0$ for (*g*), and $U_1\omega_0 = 3^{-\frac{1}{2}}$, $U_2\omega_0 = 3^{\frac{1}{2}}$, $\zeta_1 = \zeta_2 = 1.0$ for (*h*). The first factor produces 60°-phase lag, and the second factor 120°-phase lag, so that with the numerator lead of 90°, the net phase lag is 90°.

8. TOLERANCE REQUIREMENTS FOR PHASE-LAG NETWORKS.

To illustrate the method of calculation of tolerances on the components of a phase-lag network, in this section we state the results of the derivation of the variational conditions for a phase-lag network to

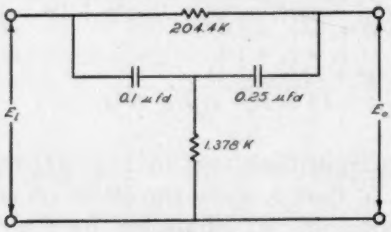

FIG. 33.

precede the bridge "T" indicated in Fig. 33 (same as Fig. 12 in section 15 of Part II). Suppose that the desired phase lag is 120°.

The input impedance to the bridge "T" at 60 cycles is replaced by an equivalent parallel condenser $C = 0.099$ μfd. and resistor $R = 0.149$

megohm. A network to give 120° phase lag and a gain of 0.203 to the bridge "T" input is as follows: input resistor $R_2 = 4.76k$, $R_0 = 27.2k$, input condenser $C_2 = 1.0\ \mu$fd., output condenser $C' = 0.1\ \mu$fd. For this phase-lag network, the tolerance requirements for phase shift of $-120°$ correct to within $\pm 5°$ are:

$$-0.168 < 0.29\Delta + 0.85\Delta_0 + 0.89\Delta_2 + 0.91\epsilon_0 + 0.95\epsilon_2,$$
$$0.24\Delta + 0.43\Delta_0 + 0.45\Delta_2 + 0.47\epsilon_0 + 0.51\epsilon_2 < 0.121,$$

where $C_0 = C' + C$, $\epsilon_0 = \Delta C_0/C_0$, $\Delta = \Delta R/R$. If Z is the impedance of R and C in parallel, $Z = R/(Tj\omega + 1)$, where $T = RC$, and

$$\frac{dZ}{Z} = \frac{dR}{R} - \frac{T\omega^2 dT}{(1 + T^2\omega^2)} - \frac{j\omega dT}{(1 + T^2\omega^2)}$$
$$= -4.45\Delta - 5.45\epsilon - 0.985j(\Delta + \epsilon).$$

From this and the expression for $\Delta Z_i/Z_i$ in section 15 of Part II, assuming 0.6 per cent tolerance on the bridge "T" components, it follows that $(\Delta C/C_0) = (a - 4.45b)/1.99$, $\Delta = (5.45b - a)$, where a and b in per cent may have any values in the intervals $-0.507 \leqq b \leqq +0.507$, $-1.327 \leqq a \leqq +1.327$. Thus $\Delta C/C_0$ cannot exceed 1.8 per cent in numerical value, and Δ cannot exceed 4.09 per cent. (These are the bounds when a and b vary independently in the expressions for $\Delta C/C_0$ and $\Delta = \Delta R/R$; we do not pause for closer examination of the expressions and of the conditions for phase lag of $120° \pm 5°$, to determine the actual bounds.) Substituting $(\Delta C/C_0) = 1.8$ per cent and $\Delta = 4.09$ per cent in the conditions for phase lag of $120° \pm 5°$, we obtain the following tolerance conditions on the components of the phase-lag network:

$$-0.140 < 0.85\Delta_0 + 0.89\Delta_2 + 0.457\epsilon' + 0.95\epsilon_2,$$
$$0.43\Delta_0 + 0.45\Delta_2 + 0.236\epsilon' + 0.51\epsilon_2 < 0.103.$$

These conditions require a uniform tolerance of -4.45 per cent, $+6.33$ per cent on R_0, R_2, C_2, C'; or, for example, if R_0, R_2 are held to within 0.1 per cent, the appropriate tolerances on C', C_2 are, respectively, -15.1, $+21.6$ and -7.27, $+10.0$ per cent. Thus if the bridge "T" components are held to ± 0.6 per cent, to insure phase shift through the bridge "T" within $\pm 10°$, these tolerances on the phase-lag network components will insure that the phase lag through the network preceding the bridge "T" is $120° \pm 5°$.

ACKNOWLEDGMENT.

The author wishes to express his appreciation of the work of Miss Virginia Driscoll. She carried through the required computations, and prepared or directed the preparation of all of the figures and charts, in the three parts of the paper. Without this assistance the publication of the paper would not have been possible.

Tube Expected to Make Fluoroscope 500 Times Brighter.—The fluoroscopic X-ray image amplifier is based on information gained in four years of intensive study resulting in the actual amplification of an X-ray image. Basically it will consist of a high vacuum tube that electrostatically focuses and accelerates an electron stream. When perfected, the device will take the form of an attachment for standard fluoroscopic equipment.

The conditions that confront the physician in present day fluoroscopy are even worse than those encountered in finding a seat in a movie after leaving the bright sunshine. To see the fluoroscopic image he has to dark-adapt his eyes for twenty minutes. Even then with the low brightness available in most difficult cases, such as a large abdominal thickness where the brightness may be as low as 0.00005 millilamberts, a separation of $\frac{1}{4}$ in. is necessary before contours can be distinguished. Furthermore this $\frac{1}{4}$ in. figure applies only in measurements where the contour lines separated regions with a contrast of 100 per cent, as in contours between black and white. While this is an extreme case it compares with 30 millilamberts brightness and 0.001 in. contour separation as normal conditions for observing X-ray plates. A brightness of 0.001 millilamberts with a required contour separation of $\frac{1}{32}$ in. is about the center of the fluoroscopic range.

The new image amplifier increases the brightness of the fluoroscopic image after the X-rays have passed through the patient. This solution to a long felt problem is necessary because the X-ray intensities are already at the patient's tolerance level and is possible because the sensitivity of the physician's eyes is the main limitation to effective fluoroscopy today. Fluorescent screens now have a gross efficiency of about 3 per cent so that even a theoretically perfect screen would be only about thirty times as bright. Thus screen improvement alone cannot achieve the desired brightness gains.

With the image amplifier tube attached to his equipment the physician will step into his dark room and see at once an image in appearance almost as bright as a movie screen. He may still have to dark-adapt his eyes, though for only 3 or 4 minutes, before he can see all the details. What he sees after that will be a clear, easily discernable feature presentation of his patient's organs at work.

Wheat Clean-up.—In the early 1930's more than half of the cars loaded with wheat that reached terminal markets in the Pacific Northwest were graded "smutty," says Dr. M. A. McCall of the U. S. Department of Agriculture. As a result of the breeding of resistant wheats in the program in which the Bureau of Plant Industry, Soils, and Agricultural Engineering cooperates with the States, new wheat varieties were introduced. Ten years later, in the early 40's, only a little more than one car of wheat in a hundred was graded "smutty."

THE CONESTOGA WAGON.

BY

THOMAS COULSON.[1]

Have you any ideas upon the origin of the expression "I'll be there with bells on"? Or why a certain form of cigar came to be called a "stogie"? There would appear to be no common denominator for the two, and both seem far remote from the history of land transportation, yet both are derived from the drivers of the Conestoga wagon in the golden age of wagoning.

In the days of the colonies the state of the roads provided the drivers of the wagons with a rich variety of minor hazards to spice their journey. Whenever one driver had to go to the aid of another in distress on the rough, slippery, or water-logged roads, it was customary to reward him with a gift of the luckless driver's hame-bells. Thus, to assure anyone that he would arrive at his destination with bells complete was an expression of absolute assurance in his ability to surmount all difficulties without outside aid.

As for the stogie, it was a long cheap cigar (sometimes a foot in length) of rough rolled leaf made especially for the taste and purse of the Conestoga wagoner. The word is simply a corruption of "Conestoga."

No form of transportation has left a deeper impression upon national life than has the "covered wagon." Although it is most popularly associated with the great days of pioneering over the wide prairies, that was not the age of its greatest splendor. Its real glory grew with the colonies as they spread out from Pennsylvania into Ohio in what was probably the most romantic period of American transportation.

Its popularity waxed with the development of the road and waned with the conquering onrush of the steam locomotive. Since the trail has been swept by the winds and beaten with the rains of more than a century, it is not surprising that it grows dimmer with the passage of the years. Nevertheless, its memory deserves to be preserved. It is not only a very significant link in the chain of transportation growth, but it merits remembrance as an example of early American craftsmanship at its stage of highest achievement.

We cannot say with any degree of assurance when the Conestoga design emerged from the more primitive straight body lines of the earliest wagons. The diarists of Colonial days were content, like George Washington, to write of "the wagons" they owned without

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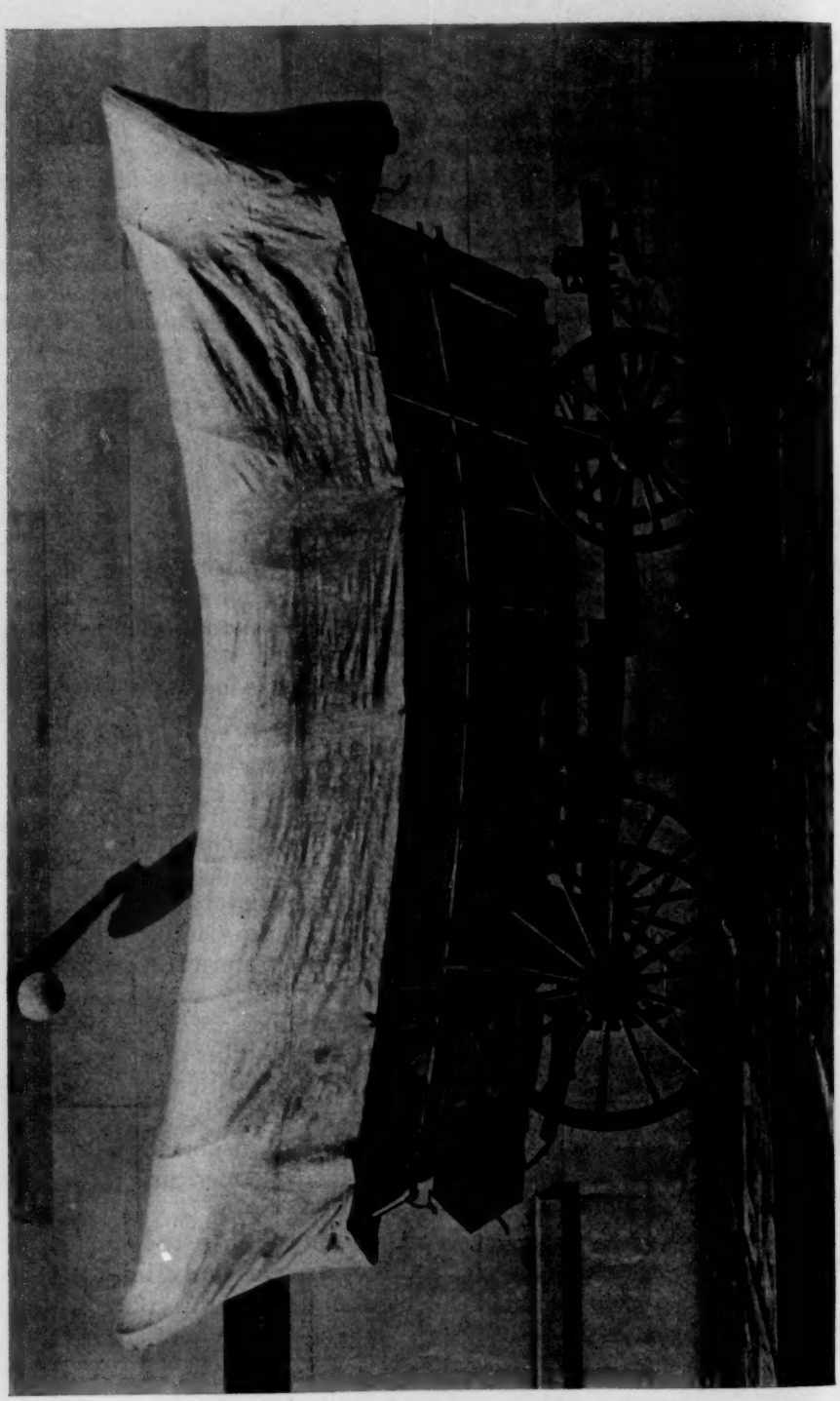

FIG. 1. The Conestoga wagon. The specimen in The Franklin Institute Museum, built about 1830.

specifying in any way the distinctive features. The first hint that any change had taken place in design comes from later writers who allude to "Dutch" and "English" wagons. Doubtless the first word applied to the popular but misapplied name given to the Germans who were the early settlers of the Conestoga Valley in Lancaster County, Pennsylvania, who made extensive use of this type of wagon.

The application of the word "English" to the wagon is not so obvious, but it probably has more justification. The design of the hay-wain has remained unaltered in England for more than 300 years. Early examples have the curved bed that is characteristic of the Conestoga. However, this feature is not peculiar to the English vehicle, as it is seen in pictures appearing in French manuscripts of the fifteenth century. The curved bottom is merely a commonplace where merchandise was transported in barrels.

What is stronger evidence of the English origin is a detail which seems to have been completely overlooked. This is the notched edge and chamfered decoration which re-appears on the end gate of the American form of wagon. This simple form of ornamentation (which may be seen on the specimen in The Franklin Institute Museum) is a traditional feature of the English hay-wain.

Nor can we find when the term "Conestoga" was first applied to the wagons of this design. The first mention in print occurs in the *Pennsylvania Gazette* of February 26, 1750, which refers to a tavern "at the sign of the Conestoga Wagon." This tavern was situated on Market Street above Fourth, in Philadelphia. Still another tavern of the same name was situated in Lancaster. It is mentioned in 1789, but as it is then spoken of as a "famous old tavern," it had probably displayed the name for several years before the year mentioned. However, we have evidence that the name was established at both ends of the turnpike which is associated with the origin of the wagon, by the middle of the eighteenth century.

In those days, Philadelphia drew the bulk of its food supply from Lancaster County. Faris says[2] that the Lancaster Turnpike was called the Conestoga Road because it was the favored route of the freight carriers. In 1794, the turnpike, 24 ft. broad and surfaced with broken stone, was opened as the first toll road in the country. It extended from Philadelphia to Lancaster, 62 miles away. This was the main artery for the city's food supply. Some twenty or thirty white-hooded wagons would follow one another along it in stately procession. But the traffic was not all in one direction.

From Lancaster the trail ran west through Columbia and Marietta over the Alleghenies to the Forks of the Ohio, or northwest to Lake Erie. Along the former route went the pack-trains and the Conestoga wagons as the country began to develop and the young nation expanded.

[2] J. F. FARIS, "Old Roads out of Philadelphia," 1917.

FIG. 1. The Conestoga wagon. The specimen in The Franklin Institute Museum, built about 1830.

It must have been a rather terrifying experience to drive one of the cumbersome vehicles over the five mountain ranges between Pittsburgh and Philadelphia, especially on the steep grades. On such journeys it was almost beyond the power of the driver to manage his horses and manipulate the clumsy brake. It became a common occurrence to offer a lift to a pedestrian who would undertake to discharge the duties of brakesman.

At the time of Commander Perry's operations on Lake Erie the ammunition trains made up of Conestoga wagons carried gunpowder from the Dupont factory on the Brandywine. Being reluctant to return to Lancaster County, where freight carriers abounded,[3] the drivers turned aside and made their way to Vermont and New Hampshire where there was need for carriers, and where their wagons were well adapted to the existing roads. From that time, the Conestoga wagon became a familiar sight in that region.

The constructional details of the wagon were largely traditional. An unwritten law decreed that the wheels and removable side boards should be colored vermilion, while the running gear should be blue. The nature of the woods employed, the types of iron braces and plates, the location of the tool-box, the feed-box, and the lazy board were all uniform. About the only thing in which an owner exercised his individual taste dwelt in the height of the wheels and the number of bows to support the cover.

Since the best of roads was none too good in rainy weather, and streams were rarely bridged, the wagon had to be sturdily built. On the average they weighed 3500 pounds when empty. The woods employed in the structure had to be as light as practicable without sacrificing strength. White oak was most generally used for the framing, black or sour gum for the hubs, hickory for the axles and singletrees, and poplar for the boards. The modern engineer, with his careful selection of alloys for specialized applications of metals, is carrying on the tradition of the old wheelwright.

Two skilled workmen were needed in the construction—the wheelwright (or wagon-maker) and the blacksmith. To complete a wagon with its equipment of feed and tool boxes, tar-bucket, jacks, bows, etc., would provide these two workers and their helpers with work for the greater part of two months, and the cost would be about $250.

Why should a wagon-builder be called a wheelwright? Well, a wagon will stand or fall by its wheels. Since Conestoga wagon wheels had to contend with a continuous succession of stiff obstacles they were often made heavier and stronger than would seem necessary. One of

[3] Although every farmer had a Conestoga wagon and was a potential carrier, we must accept with reservation the statement in Omwake's excellent book "Conestoga Six-horse Bell Teams in Eastern Pennsylvania," that there were 10,000 such wagons around Philadelphia. In the year 1794, the city had only 827 wheeled vehicles, other than wagons.

the peculiarities of these wheels is that their plane inclines outward from the hub to the rim, forming a dish shape. This feature is sometimes thought to be original in the Conestoga wagon, but some of the very earliest spoked wheels were built in this way. The purpose was to bring the lower spokes into a vertical position when a wheel sank into mire or on a cambered road or in any other circumstances where additional weight was thrown upon one wheel. Strength required that the spokes be upright. The tremendous side thrust of the heavy body of a Conestoga wagon would have caused an ordinary wheel to fold up like an accordion, when a turning was made, and the dishing of the wheel provided supplementary resistance to this side thrust.

One does not have to be an engineer to realize the uncommon skill required to set the spokes into the hubs and rim at precisely the correct angle.

Many of the Lancaster wagons were equipped with six wheels. When the wagon was to make a trip to Philadelphia or to make a journey along a good road surface, the largest pair of wheels were mounted in the rear and the second largest in front. For use on the farm, the tallest wheels were discarded, the forward wheels were put in their place, and the smallest pair was put in front.

Certain features of the construction give us a clue to the purpose for which the wagons were built. Those of the commercial carrier can be distinguished by two features. They had high sides with three adjustable chains across the top to provide the sides with additional support. The bottom had a more pronounced swell, because the barrel was the principal merchandise container. Since most things in trade—tar, sugar, tobacco, or flour—were transported in this sort of container, a wagon's cargo consisted of a variety of barrels, hogsheads, or casks. As a consequence it was elementary wisdom to take precautions to prevent them from rolling around and battering down the wagon sides. The curved bottom encouraged the containers to work toward the middle rather than against the sides of the wagon.

Lighter but bulkier loads of charcoal had less tendency to roll, so that the bottoms were not so curved but the sides were higher and more guard chains were provided. The wagon intended to convey fuel to a furnace had less swell and lower sides than the carrier's. Those used for transporting ore had still stronger and lower sides. Occasionally we find coal and ore wagons with a sliding panel or trap-door underneath to facilitate unloading. The later wagons gradually lost these distinguishing features since their use became more general and less specialized and sacks were substituted for barrels in packaging.

The example in The Franklin Institute Museum is typical of the solid construction of Conestoga wagons built about the year 1830. The wheels are characteristic of those employed in farm work, but marks of rubbing on the side indicate the fact that larger wheels were used at

some time or other. The larger pair of wheels are 4 feet high, and the smaller are 3 feet 6 inches. The body is 6 feet 8 inches high, and the bed is 13 feet 10 inches long. The over-all length is twenty-five feet nine inches. The cover has nine bows and stands ten feet from the ground. With its six-horse team this wagon would cover about sixty-five feet of road.

Although one thinks of the wagon as being the product of the wheelwright, the work of the smith is much too important to be dismissed without mention. Ever since the discovery of iron, the smith had occupied a prominent position in the community, and he lost none of his dignity through his work upon the Conestoga wagon. At first, the iron tires were not made in one piece. Instead, they were made in pieces of the same length as the felloes (the segments of the rim that supported the spokes). These were butted in the middle of the felloes to bind the joints. Examples of these pieced tires are very rare today.

The smith's skill improved rapidly as more workers could be spared from essential labor on the land and competitive labor produced better craftsmanship. The common tires came to be made from two pieces of a single bar, each long enough to go half way around the wheel, and welded at both joints. The tires varied in width from two to ten inches, but the average was four inches. At one time there was advanced a claim that the broadest tired vehicles should be exempted from payment of tolls on the turnpike, on the theory that their effect was to roll and smooth the surface rather than to wear it.

Tire making was compounded of the arts and sciences. It must have called for no little skill to handle the 150 pounds of iron forged in a brick forge, and a considerable amount of craft was required to obtain the necessary "twist." Owing to the dish shape of the wheel the inner edge of the felloes had a greater diameter than the outer edge, and the iron tire had to be twisted to compensate for this. Having regard to the tools available at the time, this must have been a ticklish job.

When the tire had been hammered to shape and welded, the time came to attach it to the wheel. This was an occasion for a ceremony which no village child willingly missed. The tire was laid flat on iron or stone blocks and a wood fire was built under it. The wooden wheel, meanwhile, stood ready on a trestle. When the tire reached the right temperature (a matter of purely empirical judgment) it was whisked out of the fire, fitted around the wheel, and hammered to a snug fit. This latter operation had to be performed at top speed and, as soon as it was completed, cold water was thrown on it to shrink the metal on the rim and to prevent charring the wood. Sometimes the wheel was suspended over a water trough, into which it was instantly plunged, and rotated in the water to hasten cooling. Speed in the operation was a matter of prime necessity because the danger always existed that it would char and ruin the woodwork. To prolong the process might render the whole

work on the wheel wasted energy, and to overdo the haste in chilling the tire exposed it to the risk of breaking. Tire making was no easy task.

Small rectangular holes were punched in the face of the tires to correspond with the ends of the spokes, and into these were driven wedges to prevent the side slip of the tires.

This did not comprise the entire contribution of the smith to the wagon. Much might be written upon the ironwork distributed over the vehicle. Since the wood had to be planed and pared to compromise between weight and strength, it was necessary to provide reinforcement at various points. All frictional surfaces had to be provided with iron rubbing plates. But not all the ironwork is of this severely utilitarian nature. Some of it gave expression to the smith's sense of decoration.

It is worth observing that the file was never used in this work. All the ornamentation was done with hammer and chisel. This called for a considerable amount of skill in the handling of the tools, as did the beating out of the metal to the required thickness.

American owners rarely followed the English example of denoting ownership by means of a small wooden board, bearing the owner's name and address, attached to the side of the wagon. The American practice was to have private marks fabricated of iron. Sometimes a Conestoga wagon is decorated with the owner's initials wrought in iron, and occasionally one finds a date. This is not always significant. Ironwork was not infrequently transferred from one wagon to another, so that, while the date is undoubtedly that of the ironwork, it may not apply to the wagon's woodwork. Dates were not scratched or scribed; they were either cut or punched with a chisel. Dates are also found at times on the wagon-jacks and wagon bodies.

Wagon-jacks were standard equipment, usually hung on the back axles. They were in frequent demand on journeys, not merely to lift the wagon over obstacles, but also because the wheels not infrequently had to be removed for oiling the bearing parts.

A certain amount of ironwork is to be found on the feed-boxes, but it is more of a practical nature, being intended to prevent the horses from gnawing on the wood. The tool-box, on the other hand, is the main object of ornamentation. The design employed is frequently the heart and tulip which appears in all forms of the Pennsylvania Dutch decoration.

In the older type of wagon the tool-boxes were large, and were located on the side of the wagon. In these boxes the wagoner carried all the small tools he might need on the journey for effecting running repairs—pincers, tongs, wrench, nails, spare straps, etc. The inevitable axe had a separate socket. The later wagons, intended to be restricted to farm use, had the tool-box mounted in front, a position they could not have occupied when a full tool-kit had to be carried.

Another conspicuous feature of the Conestoga equipment was the bells. These were usually small open bells suspended from flat hoops, with the open ends dangling down. The number of bells varied from three to six, but four were customary. Most likely the bells were adopted for exactly the same reason which had led to their earlier use in Europe, to warn travellers of the team's approach. The saddle horse did not carry bells.

All other vehicles were driven from the right, but the Conestoga wagon was driven from the left side, either from a saddled wheel horse or from a lazy board pulled out from under the left side. So strong was the influence of this type of wagon upon road transportation that the practice of driving vehicles from the left persists to this day in the country.

Such a wagon deserved a noble horse, and the Conestoga found one. Or, as Dunbar[4] would have us believe, which is not improbable, the wagon took its name from a breed of horses that were already well known. Like the wagon itself, the Conestoga horse is now only a memory. Where it came from no one appears to know, but it certainly was not the result of selective breeding upon a scientific plan. It is reported that William Penn had three Flemish stallions which he sent into Conestoga Valley, and that they were bred with Virginian mares. There is a strong resemblance between the Flemish horse and the strong, heavy, slow Conestoga. Many of the latter were black, but mixed breeding produced bays (perhaps from the Suffolk Punch strain) and, later, dappled grays. These docile animals stood over 16 hands high at the withers, and weighed about 1800 pounds at normal weight. The wheel horses were usually the heaviest and the best pair, since they performed the duties of backing and turning the wagons. When wagons declined in popularity so did this breed of noble animals. They faded before the advance of the hardy Western horse, which was lower in price and less expensive to maintain. But during their day, the Conestoga, both horse and wagon, filled a chapter in American history of transportation that we shall turn back to again and again with unfailing interest.

As the frontier was pressed steadily westward, the white-hooded wagon was a familiar sight in every migration. There was majesty in its leisurely advance. It must have been an impressive sight, that of the great wagon lumbering behind its six superb horses half covered with bear skins, or gayly decorated with fringed housings, stamping beneath their sweet-toned bells. Heroic sagas might be written about the wagoners who conducted these wagons over the rough trails that are today our automobile highways. And while they were so quickly fading into the obscurity of the past, the wheel tracks of their wagons could still be traced on the prairies. They were the pioneers of an advance that has known no retrogression.

[4] S. DUNBAR, "History of Travel in America," Vol. I. Indianapolis, Bobbs, 1915.

SCIENCE IN NATIONAL SECURITY.*

BY

SCOTT B. RITCHIE.[1]

The problem of National Security is of concern to every patriotic American. No subject today is of greater importance. To preserve our cherished way of life it is imperative that we develop and maintain adequate preparedness. This will be our greatest guarantee of peace. This means a strong healthy industry, a trained military manpower, and a sound program of research and development, to insure that in case fate should decree another national emergency, we will have in ample quantities the best possible weapons that can be produced under the existing state of the arts and sciences. In other words, our defense forces—Science, Industry, Army, Navy and Air Forces—working as a team, must be kept at maximum efficiency until peace is assured in this troubled world. Each of these is of transcending importance; none can be neglected without jeopardizing the others.

I am glad for this opportunity to discuss these matters briefly with you who are in the engineering profession, who have done so much for preparedness, and upon whom rests a responsibility to continue to fight for those things you know and I know are needed and against those things repugnant to the Nation we love. It is with the scientific phase I should like to deal, and since this subject is broad, I shall be able in this brief period with you to touch upon only a few of the more important aspects.

The primary aim of science is the welfare of our people. Our ability to protect ourselves depends upon our scientific progress. This, in turn, is dependent upon the intelligence of our people, which means that a tremendous responsibility now rests upon our educational systems to reduce the shortage of scientists and to build up a balanced force of highly intelligent people in all the essential professions. One of the greatest resources of our Nation is the intelligence of its people.

During the last war we drew heavily from the scientific knowledge accumulated by many years of basic fundamental research. Our store of knowledge needs to be replenished and enlarged by new knowledge, else we shall find ourselves wanting. We used to benefit greatly from the basic research programs carried out abroad, notably by the Germans.

* A talk presented before the Engineers Society of Pennsylvania, in Harrisburg, April 7, 1948.

[1] Colonel, Ordnance Dept. U. S. A. (Ret.); formerly Director of Projects Procurement for The Franklin Institute Laboratories; now with United States Pipe and Foundry Co., Burlington, N. J.

These sources are now largely closed to us. Research is not only desirable for the progress of the nation, it is imperative now for national security, security not only today, but in the long years ahead. Fundamental research creates scientific capital essential for progress. The nation which can produce the greatest quantity of the most destructive weapons will win in the end, and science will determine the degree of destruction. It is well to remember too that no one—no nation—now has a monopoly in science.

Many of our most important developments took years of painstaking research to bring them to fruition. An outstanding scientist engaged in industrial research recently stated that in his industry it took on the average seven years from an idea to a finished new product. Under the stress of war and with all the money we needed and all the talent we could muster, it took on the average 300 to 350 days to design, test and standardize a new tank or a piece of artillery. Radar and the atomic bomb were the results of years of fundamental, painstaking scientific effort, much of which was done abroad. With all the magnificent things that have been achieved by science and technology, I believe we have only scratched the surface in the things to come which may or may not be good for humanity, depending upon how we use them.

Many of the things developed for military purposes since the beginning of our nation have repaid their cost many times over in their use by industry and in improving our standards of living. Likewise, improvements by industry enhance our preparedness. The introduction of alloy steels, the development and improvement of manufacturing processes, interchangeability of parts, mass production, fixation of nitrogen, transportation, communication; these are a few of the many things that have originated with or have been greatly advanced by military requirements. Our success in war has been gaged by the quality of our fighting equipment—if you please—by the research back of it.

Unfortunately, the place of science in our national security, the importance of research and development to keep ahead of our potential enemies has not in the past received the attention it deserved. In World War II for the first time science and engineering were mobilized in the national interest. In the first World War we had our first experience in industrial mobilization, and due to our great industrial effort at that time the old German, Von Hindenberg, said that "America understood war." World War II was to science and technology what World War I was to industrial mobilization.

From both, one thing stands out preeminently—the value of *time*. We entered both unprepared, but in each case we escaped sudden devastation for we were thousands of miles of ocean from the immediate front and our allies were holding the enemy in check. Now all is rapidly changing, and if war should come again I doubt that we would have the time to mobilize our scientific, industrial and manpower forces as

we have had in the past. This emphasizes the urgency of doing the necessary things for national preparedness *now*, while time may yet be available.

In the last emergency, science came into its own and played a major role in the outcome. Our military people and our scientists learned to work together as a team which was an exceedingly important development, not only in the past war but for any which may come in the future.

Fortunately for us, in Japan there was a great gulf between the scientist and the military. The military people were extremely skeptical, in fact hostile to their civilian scientists. Unfortunately, the Germans were better coordinated than the Japs, yet they failed to handle their research people to their greatest advantage.

Nevertheless, even though we developed new and secret weapons never before visualized, and took a commanding lead toward the end of the war, we had strong competition from our enemies in many categories. In fact, some of the German weapons were superior to ours in the early days. They had started on their developments almost before the ink was dry on the Treaty of Versailles, while we cut back at that time so far that we scarcely had enough money to keep our most essential arsenals in standby condition. For example, in the Ordnance Department, which was the Technical Service of the Army responsible for research, design, development and procurement of the weapons for the army, the funds available for research and development averaged about $1,000,000 per year between the two wars. This is not large when it takes hundreds of thousands of dollars to develop one new tank, or a new piece of heavy artillery; or when we compare it to the more than $81,000,000 spent by Ordnance alone for research and development in fiscal year 1944, or to the $749,000,000[2] spent by all Government agencies on research and development in that year.

But, in spite of limited funds we were able to do a number of things between the two wars which were godsends when the storm broke. Let me mention a few specially concerned with Ordnance development and production.

1. We had developed the centrifugal casting process for making cannon which helped us, *especially in the early days of the war*, to meet our requirements in artillery. About one-third of all the cannon used by our armed forces were centrifugally cast.

2. The cold working or auto-frettage method for making cannon with improved strength permitting lighter weight and higher muzzle velocities.

3. Research and development at Watertown Arsenal had pioneered in the development of molybdenum high speed tool steels, thus making this country immune to a possible paralysis of industrial manufacturing due to shortage of tungsten.

[2] This figure does not include atomic bomb research.

4. The application of welding to Ordnance material, a major development resulting in weight reduction, improvement in design, greater ruggedness and economy in material, time and money.

5. The development of testing techniques such as macro-etching, radiography and impact, which contributed to improved quality and safety of performance.

6. We had designed and developed, or had drawings and specifications ready for production, such items as the .50 caliber machine gun which was 98 per cent of the gun armament of the Army airplane, and which the Commanding General of the Army Air Forces stated was the most outstanding aircraft gun of World War II; the 105-mm. Howitzer which was the workhorse of the Army artillery and which fired more rounds of ammunition than any other artillery weapon; the .30 caliber semiautomatic Garand rifle, M1, which gave our men a fire power superiority over all others, and which the enemy soldiers would risk their lives to steal from our soldiers. In a letter of 26 January 1945, General Patton wrote, "In my opinion, the M1 rifle is the greatest battle implement ever devised." Many important items such as I have mentioned had been developed between the two wars and were ready to go into production by industry in the fall of 1940 when the Ordnance Department received 1¼ billion dollars for the manufacture of equipment.

As the war clouds began to gather and funds were made available to the armed services, the tempo of research and development was progressively increased as the war days went by. Cooperative programs with science and industry for research and production were established by the armed services and constituted the ground work for the war effort. At the peak, the Ordnance Department alone had some 1500 facilities—research and engineering organizations, university and commercial laboratories—and thousands of sub-contractors engaged in its research and development program. The National Defense Research Committee was established in 1940 by the President to mobilize the Nation's scientific talent and to assist the armed services in research and development projects. The Ordnance Department sponsored more than 200 projects with NDRC, of which approximately one-half had been completed by VJ-Day. Notable in these cooperative projects were rockets and the VT fuze about which I shall speak later. The NDRC was established none too soon as the general unpreparedness of our country had given the Axis nations such a tremendous initial advantage. Perhaps Hitler made one of his greatest mistakes, possibly costing him the loss of the war, when he ordered research and development stopped and production concentrated on the then standard weapons at the time when his greatest successes led him to think there would be an early decision. About 4 months later he revoked this order. We, however, after a not too early start, foresaw the fact that the great struggle ahead would as never before be a race between scientific giants

to achieve mastery. This, as you know, culminated in the most devastating weapon of all time, the atomic bomb. Even before it was used, the outcome was evident. Germany had collapsed and the Jap homeland was being devastated by bombs from our B-29s. Let me mention only a few of the developments which made possible our success.

Military aviation, the submarine, and the armored tank, used in World War I to a limited extent, came into full use by both sides in the last conflict. Radio, used so effectively for a variety of military purposes, came into use before the war and was greatly expanded during the war. To these were added many other new weapons of destruction such as recoilless rifles, amphibious vehicles, VT or proximity fuzes, radar, new tanks, rockets, bazookas, which for the first time in history placed weapons of artillery power in the hands of the foot soldier, shaped charge ammunition, high velocity sintered carbide projectiles which can penetrate several times their caliber of armor, guided missiles, new and vastly more powerful artillery weapons, new fire control instruments which made bombing and artillery extremely accurate, and special fuzes for artillery shell which greatly aided in the demolition of concrete fortifications. We developed the greatest line of high-powered, speedy self-propelled artillery of any nation. Many of you are familiar with the 105-mm. howitzers, the 155-mm. Long Toms, the 240-mm. howitzers, not to name a multitude of other calibers which helped to give us a tremendous firepower superiority. Ranges of our artillery in general were increased 40 to 50 per cent over that in World War I. For the first time artillery was installed in our aircraft and was used with deadly effect on shipping and other opportune targets.

Our high explosives which helped to destroy the German and Jap cities were 20 per cent more powerful than those used in World War I; and certain individual new explosives were developed much beyond this figure. None of the propellent powders of 25 years ago was in use by the end of the war. They had been replaced by new and improved types. In this connection, prior to World War II, silk cloth was used as a container for propellant powder for all semi-fixed and separate loading ammunition. Silk was a strategic material because the Japs controlled practically all raw silk production and the new artificial silks, or rayons, of industry were not satisfactory due largely to the marked difference of the physical characteristics of extruded filaments and those of natural fibers. After much research Picatinny Arsenal solved this problem and provided a suitable cotton cartridge cloth to replace silk.

A development of extreme importance was the means to permit our automotive equipment, including armored tanks, to wade and swim in water. Those of you who participated in the Normandy landings or the operations in the Pacific know how important that was. The DUKW, for example, was built to run on land and in the sea and was an indispensable amphibious vehicle.

When the Japs took over the sources of natural rubber, the ingenuity of American science and industry came into play and after some difficulties, and with extensive tests carried out by the Ordnance Department in cooperation with industry, synthetic rubbers were developed which in some ways even excelled the natural rubbers. Since our armies moved on rubber, that development was a must.

Fuels and lubricants were among the three most essential items used in the war. They are the life blood of a mechanized army and received much attention. Great stress was placed on the need for a single all-purpose fuel for use in all combat and transport equipment. There was also need for a single purpose year-round recoil oil for all artillery, and for preservative oils and rust preventive compounds to protect our equipment stored and used under global conditions. One of our great problems was due to the fact that we had to provide equipment suitable for the Arctic, the desert and the tropical jungle. Innumerable problems arose under these conditions, and extensive tests were carried out in the North, in the desert and in the jungle, to solve them. These tests are still continuing.

It has frequently been said that the last war was one of metals. Certainly steel played a dominant role. Other metals were also exceedingly important and many substitutes had to be used. Our 70–30 brass, of which copper is the major element, had long been our standard for cartridge cases, but shortages of copper forced the development of steel cartridge cases. The light weight metals, aluminum and magnesium, found many applications in war equipment, but steel was the great tonnage item and many metallurgical improvements were made under the stress of war.

Prior to the emergency the metallurgy of armor and armor piercing projectiles was very much of a mystery and the few commercial companies engaged in their peace-time manufacture held the processes secret. During the war the producers shared this secret information to make the mass production of these items possible by plants scattered throughout the country.

The demand for rolled armor plate for tanks and armored vehicles could not be met and a program for developing and manufacturing cast steel armor on a grand scale was inaugurated. Starting with practically no knowledge in this country on cast armor, American foundries pooled their efforts and soon developed cast armor of suitable quality. Without this our tank program could not have been met. It might be of interest to note that body armor supplied to our aircraft crews resulted in a 50 per cent reduction in deaths and 80 per cent reduction in wounds.

I mentioned previously the centrifugal casting of cannon. To further assist in meeting the tremendous demand for cannon, the rolling of cannon barrels up to and including 75 mm. on seamless tubing mills was successfully accomplished. During the first World War the yield strength usually prescribed for cannon was around 65,000 psi. By the

end of World War II we were procuring cannon with yield strengths as high as 150,000 psi. This is a measure of metallurgical improvement, yet I am sure we have only touched the potentialities of metals.

Due to the shortage of alloys normally used in guns and armor, the alloy content had to be drastically reduced. In some cases it was cut down to one fourth or less, yet with no reduction in performance.

In the huge program of developing and producing arms and equipment, welding played a major role. We used it in mass production and to a far greater extent than did our enemies. One of the notable metallurgical achievements in this war was the development of suitable techniques for welding armor plate and armor castings which permitted the change from riveted to all-welded structures in our fighting vehicles and gave increased production and improved performance.

These were a few of the remarkable metallurgical achievements for which the Ordnance engineer, the metallurgist and the production engineer, working as a team, deserve much credit.

Great progress was made in the war against disease. This is evidenced by the fact that the death rate for all diseases in the army was reduced from 14.1 per thousand in the first World War to 0.6 per thousand in World War II. You all know what the great discoveries of sulfa drugs and penicillin have meant, and the lives saved by surgical techniques and the use of blood plasma. Research in food and clothing also did much for the comfort and welfare of our troops.

It would be inappropriate not to mention at least two research tools of great importance which were developed during the war and the use of which is now increasing, namely—the ENIAC (Electronic Numerical Integrator and Computer) and the Supersonic Wind Tunnel. Both are in operation at Aberdeen Proving Ground. These are products of research sponsored by the Ordnance Department. The ENIAC is among the foremost scientific achievements of the war. It contains some 18,000 electronic tubes and solves intricate problems a thousand times faster than any machine ever built—problems that are hopelessly beyond the scope of other methods, which opens up new fields of research to all branches of science. The other research tool, the Supersonic Tunnel, installed at Aberdeen Proving Ground, is an invaluable facility for ballistic and aerodynamic research on high velocity projectiles, bombs, guided missiles, and supersonic aircraft. The Germans also used wind tunnels extensively during the war in the development of projectiles, aircraft, and V-weapons. The value of such tools for future research is incalculable.

I have mentioned only a few of the many scientific developments which helped us to win the war. It has been said that the three greatest scientific achievements were VT fuzes, radar, and the atomic bomb. It has also been said that our greatest secret weapon was the unexcelled production capacity of American industry. Certainly the things that won the war were produced in great quantities, and the developments

alone would have been of little or no avail to crush the enemy had they not been rapidly translated into huge quantities of finished items to give the necessary fire power. A few figures on Ordnance materiel will illustrate what I mean.

In Army Ordnance alone, in World War II, there were some 1800 major items and over 600,000 principal components whose development and manufacture embraced every phase of the arts and sciences. In war things move swiftly as evidenced by the fact that 75 per cent of these 1800 major items were newly designed or radically improved after the beginning of the emergency. During the last three years of the war, more than 1000 new items were developed and brought into production. The expenditures for Ordnance materiel were ten times as much as in World War I. In weight the ratio was twenty-five to one. The Army Air Forces dropped 1,500,000 tons of bombs on western Europe between August 1942 and victory in May, 1945. At the peak of fighting 293,000,000 rounds of small arms ammunition were expended in one month. Each fighting infantryman needed 35 pounds of arms and ammunition a week. Of the $45,000,000,000 spent for Ordnance, $38,000,000,000 went for tanks, small arms, trucks, ammunition and accessories. Nearly $5,000,000,000 went into construction and equipment of government owned, contractor operated manufacturing plants. Nearly a billion dollars went for lend-lease machine tools shipped to foreign countries. Another billion was spent for additional items, including schools, research, and establishment of the Ordnance supply chain. Ordnance had the biggest segment, about 50 per cent, of the total supply task of the Army Service Forces. Roughly, Ordnance accounted for 20 per cent of the total United States war munitions effort including air forces, navy vessels and merchant marine production. There were 88,000 tanks, 133,000 miscellaneous combat vehicles, 50,000 self-propelled weapons, two and one-half million trucks, 600,000 artillery pieces and millions of such items as rifles, carbines, bayonets, helmets and grenade launchers. This was truly the most ponderous array of armed might this world has ever seen, and it was used by soldiers unexcelled anywhere, at that time.

Looking ahead, we may expect further developments in VT fuzes, radar, and the atomic bomb. Guided missiles and pilotless aircraft to operate at transonic speeds and extreme altitudes are already here. Means to combat these things must be and are being developed. Muzzle velocities and ranges of weapons two to three times those now used are in the offing. Rates of fire will be multiplied in some cases by the thousands. Transport of troops and their fighting equipment by air in another emergency will be what movement by motor was in the last. The future may see flying tanks, ships that sail under the water by atomic power, and death rays even more deadly than the atomic bomb. Who knows what the future will bring forth? Our only safety is in

scientific progress, more and more military research to be sure that we keep in the front. God only knows what would have happened to us if the Germans had beaten us to the VT fuze or the atomic bomb. The VT fuze in their hands could have wiped our air forces out of the sky. On the other hand, it has been authoritatively stated that the VT fuze saved London from the German buzz bomb, and that new apparatus for airplane detection developed by British physicists saved England. This permitted the English Spitfires to go up in time to shoot down the attacking German bombers. Your imagination is perhaps better than mine as to what an atomic war head in the German V-Rockets would have done to England and our forces in Europe. We were brought perilously close to the brink in many cases.

One of the great dangers facing us now is over-confidence. Stock piling of strategic materials is vital, and where there may be shortages, research is imperative to develop adequate substitutes or proper conservation measures. Another world war may find us seriously crippled in many essential raw materials. We must be careful not to depend upon false security which might be given by great stores of weapons, good today but obsolete tomorrow. Time moves on. France depended upon her excellent standard weapons of World War I to start World War II, while the Germans started from scratch and therefore had the most effective modern weapons, which contributed to their early success. All of you know the terrible cost of France's mistake. We cannot afford similar passive complacency.

Yet, we must not neglect our tested and tried weapons with which we ended the last war. We must always strive to be first in the development of new things, but we should not unduly extol the virtues of the new and novel and advocate the wholesale obsoletion of the weapons of the past until we are certain that the new weapons of the future are more versatile and powerful than the ones they replace, that they are suitable for use under the extreme and drastic conditions of warfare anywhere in the world and that even in the hands of an unskilled man they are more dangerous to the enemy than to ourselves. Furthermore, they must be capable of large scale manufacture to the necessary limits of precision under wartime conditions.

I am glad that the preeminent importance of research and development has finally been recognized in the National Security Law as a division of the defense organization, reporting directly to the Secretary of National Defense. This should mean a sound, coordinated program of research and development, prevent undue duplication of effort in security research, and foster the teamwork among the armed services, science, and industry which is vital for national security. This teamwork will help to provide that preparedness *now* necessary to make the aggressor take heed—the preparedness which will be our greatest assurance of the peace we all desire.

Developed Water Power of the World.—The total capacity of water-power plants of the world at the end of 1947 was 86,900,000 hp., as determined by the Geological Survey, United States Department of the Interior. The total capacity for different years is shown in the following table:

Year (December)	Total Capacity of Water-Power Plants, hp.	Comparison with 1920, Per Cent Increase
1920	23,000,000	—
1923	29,000,000	26
1926	33,000,000	43
1930	46,000,000	100
1934	55,000,000	139
1936	60,000,000	161
1938	63,900,000	178
1940	69,400,000	202
1941	71,600,000	211
1945	77,800,000	238
1947	86,900,000	278

The table shows an increase in installed capacity of water wheels from 23,000,000 hp. in 1920 to 86,900,000 hp. in 1947, a very large growth in the short period of 27 years. The increase appears to be continuing, taking the world as a whole. The shortage of fuels (oil, gas, and coal) and their increase in price make water power appear more desirable than ever. Although there was practically no increase in the United States during the last two years, in 1948 and the years immediately following there is indicated a possibility of an increase of about 1,000,000 hp. a year. The Union of Soviet Socialist Republics is reported to be building many new plants, some of large capacity. Increased activity is reported also in Canada, France, Norway, Sweden, New Zealand, and India.

Total capacities of water-power plants for the different countries are obtained from consular agents, from information in the Yearbooks published by foreign countries, from publications of the Department of Commerce, the Federal Power Commission, the International Union of Producers and Distributors of Electric Energy, and from other sources.

Because of the restrictions on the release of information and delays in publication of official Yearbooks due to the war, accurate figures for recent years of the total capacity and of the construction and destruction of water-power plants in some European and Asiatic countries have not been made available. There is considerable conflicting information on some countries, but an effort has been made in these cases to select data from the most reliable sources. The figures of capacity of water wheels used for such countries may, therefore, be considered conservative and for others, such as Germany, Korea and Taiwan, may be high. The Dnieper station in the Union of Soviet Socialist Republics was completely destroyed, but three units of 100,000 hp. each have been replaced. The figure, 86,900,000 hp. for the world at the end of 1947, should be reasonably correct.

A THEORY OF THE INTERNAL BALLISTICS OF THE "HOCH-UND-NIEDERDRUCK KANONE."

BY

J. CORNER, Ph.D.[1]

SUMMARY.

During the war the Germans developed guns with a constriction between chamber and bore, so that the pressure in the chamber was substantially higher than that in the bore. It is shown that a simple theory of such guns can be devised, which is adequate for analysis of firing trials and for testing the claims advanced for this idea. The claim of a high piezometric efficiency is not supported by this theoretical analysis.

1. INTRODUCTION.

Up to the end of the war it was taken for granted in this country that the pressure in the chamber of a gun was almost as that in the bore and at the shot; the small difference of pressure was that needed to accelerate the gases, and was therefore of the order of 10 per cent, except in hypervelocity guns. Waves of pressure had occasionally been observed

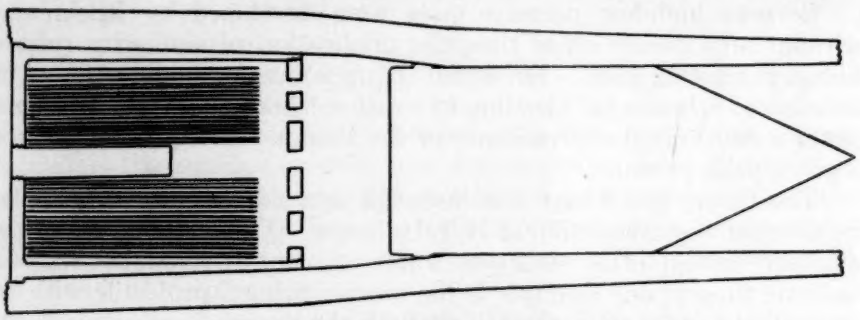

FIG. 1. A typical "hoch-und-niederdruck kanone" in section.

traveling up and down in guns, but their consequences were not welcome, and it was accepted that all well-behaved guns had nearly the same pressure at the shot base as at the breech. So far as is known to the writer, no one in Britain or America had even considered the possible advantages of deliberate differences of pressure between chamber and bore.

Investigations in Germany in 1945 revealed that this radical innovation had been studied by German engineers, and had been used in two light anti-tank guns, of which one, the 8-cm. PAW 600, was all but in service. The idea of separating bore from chamber by a nozzle, to keep up the pressure in the chamber (Fig. 1), was apparently due to Dr. Herrmann (Rheinmetall), and was patented early in the war. The first application to a service weapon was made in 1944, when a demand

[1] Armament Research Department, Ministry of Supply, England.

arose for a light but accurate projector for an 8-cm. hollow-charge projectile. Now the penetration of a hollow-charge of given diameter is insensitive to the strength of the case; thus a low bore pressure means a light-walled projectile and therefore a low muzzle-energy for a given penetration at a given range. On the other hand, a low-pressure gun of conventional type needs a big chamber, a bulky cartridge case, and a charge somewhat bigger than normal. Furthermore, the regularity of burning is asserted (by German engineers) to fall off as the chamber pressure is reduced. A plate held in the front of the cartridge case, carrying nozzles to throttle the flow, gives the advantages of a low bore pressure without the faults of a low chamber pressure. The aim of the "high-low pressure principle" (abbreviated to "H/L" in this paper), in its application to the 8-cm. PAW 600, was therefore the production of a light weapon with good regularity.

There is no suggestion in this argument that the H/L piece can be expected to be substantially lighter for a given muzzle-energy. Comparing the 8-cm. H/L gun with earlier German anti-tank guns, there is no improvement to be seen in regard to muzzle-energy per unit of total weight.

German high-low pressure guns were developed by Rheinmetall without any theory other than the application of similarity rules to firings in existing guns. Dr. Bloch (Krupps) used a modification of the solution of Schmitz (6),[2] leading to a rather laborious process and sometimes a substantial overestimate of the muzzle-velocity obtained from a given peak pressure.

The theory given here was intended as a simple and easily-applied method for the calculation of H/L ballistics. The method can be used also for certain other weapons which are not covered by orthodox ballistic theory; one example is the mortar firing a projectile with primary charge housed in the tail-shaft in the conventional manner, and another is the rocket discharged from a closed projector.

2. THE PROBLEM AND THE APPROXIMATIONS MADE.

Let A be the bore area of the gun. The cordite is contained in a first chamber of volume U_1, and before the shot begins its motion there is a total volume $U_1 + U_2$ behind it. Let S be the throat area of the venturi or nozzles connecting the cordite chamber to the bore. Let the weights of projectile and charge be W and C. Frictional resistance is included by using an effective shot mass W_1. Let δ be the density of the cordite. Let η be the covolume of the propellant gases, whose equation of state is therefore

$$p(v - \eta) = nRT,$$

where p is the pressure, v the volume per unit mass, and n the mean molecular weight.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

Let $V(x)$ be the velocity of the projectile at a travel x from its initial position. Let $C\phi(t)$ be the amount of cordite burnt up to time t and let $CN(t)$ be the mass of gas in the cordite chamber.

Let $P_1(t)$ be the pressure in this chamber, $P_2(t)$ the space-mean pressure in the bore. The pressure is assumed to be uniform throughout the cordite chamber. The conventional Lagrange correction for pressure-gradient between breech and shot-base makes the pressure accelerating the shot $P/(1 + C/3W_1)$, where P is the space-mean pressure. The hydrodynamic conditions in the new type of gun are rather different, but if the same relation is used the error is likely to be no greater than that incurred by using the conventional pressure gradient in orthodox ballistics. This error is much greater than one would expect from a comparison of various theoretical solutions, which are very similar and all at variance with recent experimental findings. This is a matter which cannot be discussed further in this paper. However, in a "high-low pressure" gun the low bore pressure guarantees a low value of C/W, so that the pressure gradient is of small importance and errors in it of still less moment.

For the law of burning of the propellant it is assumed in this paper that

$$D\frac{d\phi}{dt} = \beta P_1. \tag{1}$$

This is approximately correct for propellant in tube and ribbon shapes, where D is the annulus or thickness, respectively. With D about 25 per cent greater than the least distance between perforations, (1) gives a reasonable fit to the ballistics of orthodox guns firing 7-hole multitubular chopped grains of the American type. Only for charges in cord form is (1) inadequate.

β is the rate of burning of the propellant. The effects of the resistance to engraving of the driving band of the projectile will be simulated by an increase in β. If this increase is chosen to give the same effect on peak pressure as physically more plausible representations, the effects on the muzzle velocity are nearly the same in both models; this is true whether the initial resistance is represented by a shot-shot pressure falling to zero immediately the projectile moves, or by a resistance which is a continuous function of the travel, with an initial peak. Empirically, the use of an effective β, varying with the charge conditions, is always possible, and the variation of β is in fact much more special and certainly more convenient than could have been expected: the effective rate β is a function of the peak pressure only, for given gun and projectile.

The equations of internal ballistics are greatly simplified by the approximation that the temperature of the propellant gases is constant during the period of burning. In practice there is a fall due to the work

done on the shot. This decay is roughly linear in the travel, and attains about 10 per cent when the propellant is completely burnt. The approximation of constant temperature was introduced by Moisson (4), who applied it also to the adiabatic expansion after the gunpowder had burnt, a period in which the approximation is very rough; Mata (3) also used the isothermal approximation. It has not been used much in the Continental literature since that time, perhaps because the approximation is useful rather than elegant. The isothermal model has been much used in the British school of ballistics, as, for example, by Clemmow (1). This is partly because it simplifies the analysis at a point which is not usually of primary interest in these investigations; another reason will appear in a moment.

Three important approximations have been introduced up to this point: (*a*) the burning law (1), linear in the pressure; (*b*) the simulation of the effects of initial resistance by a change in β; (*c*) the isothermal approximation. A theory based on these three approximations has been used in Britain for many years for the routine estimation of charges for orthodox guns. If the rate of burning is chosen to give the observed peak pressure the theoretical muzzle-velocity comes within a few per cent of the fired value. This agreement is sufficiently close to enable the error to be predicted from existing firings of a similar type, while empirical rules have been developed for the prediction of effective rates of burning. Thus a ballistic scheme has been evolved, in which a mass of ballistic data is tied together by this simple approximate theory. In the present paper the same fundamental approximations are used in a theory of the "high-low pressure gun," and it is assumed that the general behavior of such guns will be reproduced with the same accuracy as in the analogous theory for orthodox guns.

The pressures at inlet and exit of the nozzle are P_1 and P_2. Let γ be the ratio of the specific heats at constant pressure and volume for the propellant gases. If

$$\frac{P_2}{P_1} < \left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}, \qquad (2)$$

then the rate of flow is settled by P_1 alone. This is a familiar result in the one-dimensional theory of nozzles. There should, as a matter of fact, be a covolume correction to this critical ratio, the magnitude of which has been worked out by Rateau (5) and which amounts to about 7 per cent for $\gamma = 1.25$ when $P_1 = 25$ tons per square inch, towards the upper limit of the ballistic range. For this value of γ, the condition (2) is $P_2/P_1 < 0.555$.

The covolume also alters the rate of flow at a given pressure; it can be shown that the error is less than 7 per cent for pressures up to 25 tons per square inch. In this paper the covolume effects on the flow between the two chambers will be neglected, but *not* the direct effect on the equation of state.

For P_1 and P_2 satisfying (2), the rate of flow is

$$\psi \frac{SP_1}{\sqrt{\lambda}}, \tag{3}$$

where ψ is a numerical factor which depends on γ but lies within 1 per cent of 0.66 for all Service propellants. A correction for friction and heat losses in the nozzle should be added to ψ; a 5 per cent reduction, which is reasonable, makes ψ about 0.63.

If P_2/P_1 is greater than the limit mentioned in (2), the rate of flow is

$$\frac{\chi SP_1}{\sqrt{\lambda}} \left(\frac{P_2}{P_1}\right)^{0.8} \left[1 - \left(\frac{P_2}{P_1}\right)^{0.2}\right]^{\frac{1}{2}}, \tag{4}$$

where χ is 3.162 for $\gamma = 1.25$ and no friction losses. With allowance for friction one may take $\chi = 3.00$. Another way to express the difference between (4) and (3) is by their ratio, which can be regarded as the factor representing the effect of back-pressure on the flow. Table I

TABLE I.—*The Back-pressure Factor.*

P_2/P_1	Factor	P_2/P_1	Factor
0.56	1	0.94	0.507
0.6	0.995	0.96	0.419
0.7	0.948	0.98	0.300
0.8	0.840	0.99	0.214
0.85	0.755	0.997	0.117
0.9	0.638	1	0

shows some typical values, and is useful in approximate calculations when P_2/P_1 exceeds 0.55.

It will be assumed that P_2/P_1 remains throughout at less than the critical value (2). The great simplicity which this introduces into the mathematics will be seen later. The German guns actually built did satisfy this restriction, though they had been considering types for which (2) would not hold. Provided P_2/P_1 and hence the "back-pressure factor" do not vary too much during the firing, the theory of this paper can be used as a guide when P_2/P_1 exceeds 0.555. As P_2/P_1 approaches unity the solution given here becomes less and less accurate, regarded as a solution of the basic equations.

It is assumed that no unburnt cordite passes the nozzle. This is probably true in the later types of H/L guns with a number of small nozzles in parallel between the two chambers. With normal ignition no appreciable error is expected from this assumption.

3. EQUATIONS OF INTERNAL BALLISTICS, UP TO "BURNT."

3.1 The Cordite Chamber.

The equation of state for the gas in the first chamber is

$$P_1\left\{U_1 - \frac{C(1-\phi)}{\delta} - CN\eta\right\} = C\lambda N \tag{5}$$

and for that in the second chamber and bore is

$$P_2\{U_2 + Ax - C(\phi - N)\eta\} = C\lambda(\phi - N), \tag{6}$$

where λ is written for the mean value of nRT during the period of burning of the propellant. The same λ applies to both the bore and the cordite chamber.

Also

$$\frac{dN}{dt} = \frac{d\phi}{dt} - \frac{\psi S P_1}{C\lambda^{\frac{1}{2}}},$$

which by (1) is

$$\frac{dN}{dt} = \left\{1 - \frac{\psi SD}{\beta C\lambda^{\frac{1}{2}}}\right\}\frac{d\phi}{dt},$$

with the initial condition $N = \phi = 0$. Hence

$$N = (1 - \Psi)\phi, \tag{7}$$

where

$$\Psi = \frac{\psi SD}{\beta C\lambda^{\frac{1}{2}}}. \tag{8}$$

This dimensionless parameter Ψ, which is of order 0.5, was found to play a fundamental part in the ballistics of recoilless guns (2), where S was the throat area of the venturi in the breech. Ψ plays an equally important part in the theory of the H/L gun.

Substituting from (7) into (5),

$$C\lambda(1-\Psi)\phi = P_1\left\{U_1 - \frac{C}{\delta} + \frac{C\phi}{\delta} - C\eta(1-\Psi)\phi\right\}$$

$$= P_1\left[U_1 - \frac{C}{\delta} - C(1-\Psi)\phi\left\{\eta - \frac{1}{\delta(1-\Psi)}\right\}\right]. \tag{9}$$

Thus the pressure builds up in the first chamber as if it were a closed vessel with charge $C(1-\Psi)$, covolume η, propellant density $\delta(1-\Psi)$, and web-size D.

From (1) and (9),

$$\frac{d\phi}{dt} = \frac{\beta C\lambda(1-\Psi)\phi}{D[U_1 - C/\delta - C\phi\{\eta(1-\Psi) - 1/\delta\}]}$$

$$= \frac{\mu\phi}{1 + b\phi}, \tag{10}$$

where

$$\mu = \frac{\beta C\lambda(1-\Psi)}{D(U_1 - C/\delta)} \tag{11}$$

and

$$b = \frac{C\{1/\delta - \eta(1 - \Psi)\}}{U_1 - C/\delta}. \tag{12}$$

Note that b may have either sign, and is usually smaller than the analogous "covolume term"

$$C\left(\frac{1}{\delta} - \eta\right) \Big/ (U_1 - C/\delta)$$

for an orthodox gun. Taking the origin of time when $\phi = 1$, the solution of (10) is

$$\phi e^{b(\phi-1)} = e^{\mu t}. \tag{13}$$

The pressure in the first chamber is

$$P_1 = \frac{C\lambda(1 - \Psi)}{(U_1 - C/\delta)}\left(\frac{\phi}{1 + b\phi}\right), \tag{14}$$

whose maximum value always occurs at "burnt" and is

$$P_{1m} = \frac{C\lambda(1 - \Psi)}{(U_1 - C/\delta)(1 + b)}. \tag{15}$$

3.2 The Second Chamber and Bore.

The equations for the second chamber and bore are simply

$$W_2 \frac{dV}{dt} = AP_2, \tag{16}$$

where

$$W_2 = W_1 + \tfrac{1}{3}C \tag{17}$$

and

$$P_2 = \frac{C\Psi\lambda\phi}{U_2 + Ax - C\Psi\eta\phi}. \tag{18}$$

Hence

$$\frac{dV}{d\phi} = \frac{\lambda C\Psi(1 + b\phi)}{W_2\mu\left(\frac{U_2}{A} + x - \frac{\eta C\Psi}{A}\phi\right)}. \tag{19}$$

If $U_2 \neq 0$, then for small ϕ

$$P_2 = \frac{C\Psi\lambda\phi}{U_2} \quad \text{and} \quad P_1 = \frac{C\lambda(1 - \Psi)}{U_1 - C/\delta},$$

so that initially

$$(U_2 \neq 0) \quad P_2/P_1 = \frac{\Psi}{(1 - \Psi)}\frac{(U_1 - C/\delta)}{U_2}. \tag{20}$$

Returning to (19) with

$$X = \mu\left(\frac{U_2}{A} + x\right)\left(\frac{W_2}{\lambda C\Psi}\right)^{\frac{1}{3}}, \tag{21}$$

then

$$\frac{d}{d\phi}\left[\frac{\phi}{(1+b\phi)}\frac{dX}{d\phi}\right]=\frac{1+b\phi}{X-\nu\phi}, \tag{22}$$

where

$$\nu=\frac{\mu\eta}{A}\left(\frac{W_2C\Psi}{\lambda}\right)^{\frac{1}{2}}. \tag{23}$$

b and ν will both be small. It is easy to show that ν is roughly $2\eta\bar{P}/\lambda$, where $\bar{P}$ is the space-mean pressure on the shot up to "burnt." For a gun working at $\bar{P}=8$ tons per square inch, which is not likely to be exceeded in H/L guns, ν is less than 0.3. The value of b increases with the density of loading, and for a density of loading of 0.8 gm. per cubic centimeter the limits of b are -0.6 and $+1$. For practical values of Ψ the range of b values is -0.5 to $+0.5$. One may expect, therefore, that for H/L guns b will usually be small but larger than ν.

The solution which passes through $X=0$ at $\phi=0$ is

$$X=2\phi^{\frac{1}{2}}+\frac{\nu}{5}\phi+\left(\frac{4b}{5}+\frac{4\nu^2}{125}\right)\phi^{\frac{1}{2}}+\frac{44}{425}b\nu\phi^2 + \frac{19}{325}b^2\phi^{5/2}+0(b\nu\phi^{5/2})+0(\nu^3\phi^2). \tag{24}$$

This is the solution for the special class of guns with $U_2=0$. In terms of X and ν, for all solutions

$$P_2=\frac{\mu(W_2C\Psi\lambda)^{\frac{1}{2}}}{A}\left(\frac{\phi}{X-\nu\phi}\right). \tag{25}$$

For the particular solution (24),

$$P_2=\frac{\mu(W_2C\Psi\lambda\phi)^{\frac{1}{2}}}{2A}\left[1+\frac{2\nu}{5}\phi^{\frac{1}{2}}+\left(\frac{18\nu^2}{125}-\frac{2b}{5}\right)\phi - \frac{158}{425}b\nu\phi^{\frac{1}{2}}+\frac{17}{130}b^2\phi^2+\cdots\right]. \tag{26}$$

The maximum of P_2 occurs at $\phi=1$ unless $b>\frac{5}{6}$, and even then only if ν is small. For a density of loading of 0.9 gm. per cubic centimeter, b is greater than $\frac{5}{6}$ only if $\Psi>0.74$, while for lower densities of loading Ψ must be greater still; for example, at a density of loading of 0.7 gm. per cubic centimeter the peak of P_2 always occurs at $\phi=1$. Hence it is only in the most extreme cases that $P_2(\phi=1)$ will not be the maximum pressure P_{2m}, and even here they will agree closely. Therefore

$$P_{2m}=\frac{\mu(W_2C\Psi\lambda)^{\frac{1}{2}}}{2A}\left[1+\frac{2\nu}{5}+\frac{18\nu^2}{125}-\frac{2b}{5}\right] \tag{27}$$

and

$$\frac{P_{2m}}{P_{1m}} = \frac{\beta(1+b)(\lambda C W_2 \Psi)^{\frac{1}{2}}}{2AD}\left[1 + \frac{2\nu}{5} + \frac{18\nu^2}{125} - \frac{2b}{5}\right]. \tag{28}$$

For values of ϕ less than unity, P_2/P_1 is nearly proportional to $\phi^{-\frac{1}{2}}$. On going back in the solution towards smaller values of ϕ, one arrives always at a state in which the basic assumption $P_2/P_1 < 0.555$ is violated. This means that the particular solution (24) is not a physically acceptable solution for small ϕ, though it is of course an exact solution of the equation (22). The paradox that $P_2/P_1 \to \infty$ as $\phi \to +0$ is of no physical significance; this behavior would be eliminated in a real gun by Ψ tending to zero as P_2/P_1 approached unity.

The velocity V corresponding to (24) is

$$V = \frac{\phi}{(1+b\phi)}\left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}\frac{dX}{d\phi}$$

$$= \left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}\left[\phi^{\frac{1}{2}} + \frac{\nu}{5}\phi + \left(\frac{b}{5} + \frac{6\nu^2}{125}\right)\phi^{\frac{3}{2}} + \frac{3}{425}b\nu\phi^2 - \frac{7}{130}b^2\phi^{5/2} + \cdots\right] \tag{29}$$

and the velocity at "burnt" is

$$V_B = \left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}\left[1 + \frac{\nu}{5} + \frac{b}{5} + \frac{6\nu^2}{125} + \frac{3b\nu}{425} - \frac{7b^2}{130} + \cdots\right]. \tag{30}$$

The particular solution obtained up to the present applies only if $U_2 = 0$. A series solution can be found if $U_2 \gg Ax_B$. This solution is

$$X = X_0 + \frac{\phi}{X_0} + \left[\frac{3b}{4X_0} + \frac{(\nu X_0 - 1)}{4X_0^3}\right]\phi^2 + \left[\frac{(\nu X_0 - 1)^2}{9X_0^5} - \frac{(\nu X_0 - 1)}{36X_0^5} - \frac{b}{12X_0^3} + \frac{5b(\nu X_0 - 1)}{18X_0^3} + \frac{b^2}{6X_0}\right]\phi^3 + \cdots. \tag{31}$$

The corresponding pressure is

$$P_2 = \frac{\phi\mu(W_2 C\lambda\Psi)^{\frac{1}{2}}}{AX_0}\left[1 + \frac{(\nu X_0 - 1)\phi}{X_0^2} + \left\{\frac{(1-\nu X_0)}{4X_0^4} + \frac{(1-\nu X_0)^2}{X_0^4} - \frac{3b}{4X_0^2}\right\}\phi^2 + \left\{\frac{(\nu X_0 - 1)^3}{X_0^6} - \frac{7(1-\nu X_0)^2}{12X_0^6} + \frac{b}{12X_0^4} + \frac{16b(1-\nu X_0)}{9X_0^4} - \frac{b^2}{6X_0^2}\right\}\phi^3 + \cdots\right] \tag{32}$$

and the velocity is

$$V = \frac{1}{X_0}\left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}\left(\frac{\phi}{1+b\phi}\right)\left[1+\left\{\frac{3b}{2}+\frac{(\nu X_0-1)}{2X_0^2}\right\}\phi\right.$$
$$+\left\{\frac{(\nu X_0-1)^2}{3X_0^4}+\frac{(1-\nu X_0)}{108X_0^4}-\frac{b}{4X_0^2}\right.$$
$$\left.\left.+\frac{5b(\nu X_0-1)}{6X_0^2}+\frac{b^2}{2}\right\}\phi^2+\cdots\right]. \quad (33)$$

For $X_0 \geqslant 5$ this solution is convenient and accurate. For non-zero values of X_0 such that these series do not converge sufficiently rapidly, it is best to integrate (22) numerically. The boundary conditions are that $\phi\frac{dX}{d\phi} = 0$ and $X = X_0$ at $\phi = 0$. Since for the analysis of routine firings one is interested only in the pressure, velocity, and travel at "burnt," $\phi = 1$, the most useful results can be tabulated very simply, as in Tables II, III, and IV. Here are given X and $dX/d\phi$, both at

TABLE II.—*Values of $X/(2+X_0)$ at "Burnt," as a Power-series in b and ν.*
(The coefficients should be interpolated linearly with respect to X_0.)

X_0					
0	1.000	$+0.400b$	$+0.032b^2$	$+0.100\nu$	$+0.05b\nu$
0.05	0.964				
0.1	0.928				
0.15	0.894				
0.2	0.861	$+0.355b$			
0.25	0.830			$+0.095\nu$	
0.3	0.801				
0.35	0.773				
0.4	0.747	$+0.308b$			
0.45	0.724				
0.5	0.703		$+0.030b^2$	$+0.085\nu$	$+0.05b\nu$
0.55	0.687				
0.6	0.674	$+0.262b$			
0.65	0.662				
0.7	0.651	$+0.239b$			
0.75	0.642			$+0.065\nu$	
0.8	0.634	$+0.218b$			
0.9	0.621	$+0.198b$			
1.0	0.611	$+0.181b$	$+0.025b^2$	$+0.045\nu$	$+0.03b\nu$
$1\frac{1}{8}$	0.604	$+0.162b$			
$1\frac{1}{4}$	0.600	$+0.146b$		$+0.033\nu$	
$1\frac{3}{8}$	0.600	$+0.132b$			
$1\frac{1}{2}$	0.602	$+0.120b$	$+0.020b^2$	$+0.025\nu$	
$1\frac{3}{4}$	0.609	$+0.100b$			
2	0.618	$+0.084b$	$+0.016b^2$	$+0.015\nu$	$+0.01b\nu$
$2\frac{1}{2}$	0.641	$+0.061b$	$+0.013b^2$	$+0.009\nu$	
3	0.665	$+0.047b$	$+0.010b^2$	$+0.005\nu$	
$3\frac{1}{2}$	0.688	$+0.037b$	$+0.007b^2$	$+0.002\nu$	
4	0.708	$+0.030b$	$+0.005b^2$	$+0.000\nu$	
$4\frac{1}{2}$	0.726	$+0.025b$	$+0.003b^2$		
5	0.743	$+0.021b$	$+0.002b^2$	$+0.000\nu$	$+0.01b\nu$

TABLE III.—*Values of* $\left(\frac{1+X_0}{1+b}\right)\frac{dX}{d\phi}$ *at "Burnt."*

(The coefficients should be interpolated linearly with respect to X_0.)

X_0					
1.1	1.425	$+0.515b$	$-0.081b^2$	$+0.401\nu$	$+0.07b\nu$
1.3	1.410	$+0.542b$		$+0.378\nu$	
1.5	1.392	$+0.560b$	$-0.070b^2$	$+0.350\nu$	$+0.125b\nu$
$1\frac{3}{4}$	1.368	$+0.576b$			
2	1.344	$+0.585b$	$-0.054b^2$	$+0.285\nu$	$+0.12b\nu$
$2\frac{1}{4}$	1.322	$+0.590b$			
$2\frac{1}{2}$	1.301	$+0.593b$	$-0.034b^2$	$+0.234\nu$	$+0.115b\nu$
3	1.264	$+0.592b$	$-0.016b^2$	$+0.200\nu$	$+0.10b\nu$
$3\frac{1}{2}$	1.234	$+0.587b$	$-0.008b^2$	$+0.174\nu$	$+0.09b\nu$
4	1.210	$+0.580b$	$-0.000b^2$	$+0.152\nu$	$+0.08b\nu$
$4\frac{1}{2}$	1.191			$+0.135\nu$	
5	1.175	$+0.564b$	$+0.037b^2$	$+0.123\nu$	$+0.05b\nu$

TABLE IV.—*Values of* $\frac{1}{1+b}\frac{dX}{d\phi}$ *at "Burnt."*

(The coefficients should be interpolated linearly with respect to X_0.)

X_0					
0	1.000	$+0.217b$	$-0.070b^2$	$+0.210\nu$	$+0.00b\nu$
0.05	1.018				
0.1	1.027	$+0.226b$		$+0.235\nu$	
0.15	1.029				
0.2	1.025	$+0.234b$		$+0.253\nu$	
0.25	1.015				
0.3	1.000	$+0.241b$		$+0.264\nu$	
0.4	0.965	$+0.247b$		$+0.268\nu$	
0.5	0.924	$+0.251b$	$-0.056b^2$	$+0.265\nu$	$+0.01b\nu$
0.6	0.881	$+0.253b$		$+0.257\nu$	
0.7	0.837	$+0.254b$		$+0.247\nu$	
0.8	0.795	$+0.253b$		$+0.233\nu$	
0.9	0.754	$+0.252b$		$+0.220\nu$	
1.0	0.715	$+0.249b$	$-0.042b^2$		$+0.03b\nu$
1.1	0.678	$+0.245b$		$+0.191\nu$	

$\phi = 1$. From these can at once be obtained the maximum pressure in the bore,

$$P_{2m} = \frac{\mu(W_2 C\Psi\lambda)^{\frac{1}{2}}}{A(X_B - \nu)}, \tag{34}$$

the travel at "burnt" equals

$$\frac{(X_B - X_0)}{\mu}\left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}, \tag{35}$$

and the velocity at "burnt" equals

$$\frac{1}{1+b}\left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}} \cdot \left(\frac{dX}{d\phi}\right)_B. \tag{36}$$

Linear interpolation leads to errors of, in the worst case, 0.002 in $X_B/(2 + X_0)$ and 1 in 400 in $(dX/d\phi)_B$. Other errors can arise from the approximate representation of the computed results, so that the possible errors quoted just above should be doubled. This accuracy is ample in view of the simple assumptions underlying this theory, and is greater than the accuracy with which the analogous theory represents the behavior of orthodox guns.

It has already been shown that if $U_2 = 0$ the maximum of P_2 occurs at "burnt," except in extreme cases. Now an increase of the chamber volume of a gun causes the maximum pressure to occur at larger values of ϕ. Hence it is seen, and this can also be verified from the numerical solutions, that it is only in the most extreme cases that the peak bore pressure does not occur at "burnt."

4. INTERNAL BALLISTICS AFTER "BURNT."

So long as $P_2/P_1 < 0.555$, the gas flow from the first chamber is the same as if P_2 were zero, and the rate of decay of pressure P_1 is given by Hugoniot's theory with Rateau's corrections for covolume. It is probable, however, that covolume corrections will be small in all practical "high-low pressure" guns. In such a case,

$$P_1 = \frac{C(1 - \Psi)\lambda}{U_1 - \eta C(1 - \Psi)} \left(1 + \frac{t}{\theta}\right)^{-2\gamma/\gamma-1} \tag{37}$$

and

$$N = (1 - \Psi) \left(1 + \frac{t}{\theta}\right)^{-2/\gamma-1}, \tag{38}$$

where

$$\theta = \frac{2U_1}{(\gamma - 1)\psi S\sqrt{\lambda}}. \tag{39}$$

The gas in the second chamber and bore also expands adiabatically. The equations are

$$P_2 = \frac{C\lambda(1 - N)T'}{U_2 + Ax - C(1 - N)\eta} \tag{40}$$

and

$$W_2 \frac{d^2x}{dt^2} = AP_2 \tag{41}$$

together with the equation of energy

$$\frac{C\lambda}{\gamma - 1}\{\Psi - (1 - N)T'\} = \tfrac{1}{2}W_2 \left\{\left(\frac{dx}{dt}\right)^2 - \left(\frac{dx}{dt}\right)_B^2\right\}, \tag{42}$$

where T' is written for the ratio of the gas temperature to the mean value which it had during burning. Suffix B refers to conditions at

"burnt." Differentiating (42) and using (40) and (41),

$$T' \frac{dN}{dt} - (1 - N) \frac{dT'}{dt} = \frac{(\gamma - 1)(1 - N)T'Adx}{\{U_2 + Ax - C(1 - N)\eta\}dt},$$

which integrates to

$$\log \left\{ \frac{(1 - N)T'}{\Psi} \right\} = - (\gamma - 1) \log \left\{ \frac{U_2 + Ax - C(1 - \bar{N})\eta}{U_2 + Ax_B - C(1 - \bar{N})\eta} \right\}. \quad (43)$$

To obtain the muzzle-velocity, therefore, it is possible to guess $\bar{N}$ for the period after "burnt," determine $(1 - N)T'$ from (43), and the muzzle-velocity from (42). The mean velocity after "burnt" gives the epoch of shot-ejection and so, from (38), the value of N at that instant. It is then verified that the first $\bar{N}$ was sufficiently accurate.

Finally one must insert the value of $(1 - N)T'$ in (40) and the estimate for the time of shot-ejection in (37) and examine whether P_2/P_1 is still less than 0.555 at the muzzle.

Although (38) and (39) apply only if P_2/P_1 is less than 0.555, the equations (42) and (43) are always true. If P_2/P_1 is greater than 0.555 for part or all of the period after "burnt," ψ in (39) should be multiplied by an appropriate "back-pressure factor" from Table I. (38) can still be used, as an approximation, with the new and larger value of θ, when finding $\bar{N}$ for the period after "burnt."

5. SUMMARY OF THE WORKING FORMULAE.

In practice one is usually interested only in certain salient features of the ballistic solution. The first of these is the peak pressure in the cordite chamber:

$$P_{1m} = \frac{C\lambda(1 - \Psi)}{(U_1 - C/\delta)(1 + b)}, \quad (15)$$

where

$$\Psi = \frac{\psi SD}{\beta C\sqrt{\lambda}} \quad (8)$$

and

$$b = \frac{C\left\{\frac{1}{\delta} - \eta(1 - \Psi)\right\}}{U_1 - C/\delta}. \quad (12)$$

If P_2/P_1 is found to be greater than 0.555 for all or part of the time, ψ is multiplied by an appropriate "back-pressure factor" from Table I.

One can calculate

$$\mu = \frac{\beta C\lambda(1 - \Psi)}{D(U_1 - C/\delta)} \quad (11)$$

and from the initial volume U_2 of the second chamber

$$X_0 = \frac{\mu U_2}{A}\left(\frac{W_2}{\lambda C \Psi}\right)^{\frac{1}{3}}, \tag{21}$$

where

$$W_2 = W_1 + \tfrac{1}{3}C.$$

One needs also

$$v = \frac{\mu \eta}{A}\left(\frac{W_2 C \Psi}{\lambda}\right)^{\frac{1}{3}}. \tag{23}$$

From Table II are obtained X and $dX/d\phi$ at "burnt." Then the peak pressure in the bore is

$$P_{2m} = \frac{\mu (W_2 C \Psi \lambda)^{\frac{1}{3}}}{A(X_B - v)}, \tag{34}$$

the travel at "burnt" is

$$X_B = \frac{(X_B - X_0)}{\mu}\left(\frac{\lambda C \Psi}{W_2}\right)^{\frac{1}{3}}, \tag{35}$$

and the velocity at "burnt" is

$$\frac{1}{1+b}\left(\frac{\lambda C \Psi}{W_2}\right)^{\frac{1}{3}}\left(\frac{dX}{d\phi_1'}\right)_B. \tag{36}$$

The muzzle-velocity follows by the process described at the end of the preceding section.

6. THE MAXIMUM POSSIBLE PIEZOMETRIC EFFICIENCY.

As an illustration of the kind of problem which can be investigated by the methods of this paper, one may take the question of the maximum possible piezometric efficiency of a high-low pressure gun. By the piezometric efficiency is meant the ratio of the mean accelerating pressure during shot travel to the peak pressure, the term being due to Zaroodny. The interest in this particular problem arises from certain German engineers having claimed that a H/L gun can be designed to give a higher piezometric efficiency than can be obtained from any orthodox gun. This claim was not put forward by the inventor nor is it supported by the guns which were built, though as these were designed for high regularity the low piezometric efficiency is only to be expected.

The theoretical maximum piezometric efficiency obtainable from orthodox guns depends to some extent on the details of the theory used, and, in particular, on the type of resistance which is assumed to oppose the motion of the shot. Various theories give results between 85 and 90 per cent. It is clear that in any event 85 per cent is possible, so that the room for improvement by the H/L principle is small.

Consider now an H/L gun for which $P_2/P_1 < 0.555$ throughout the firing. The maximum piezometric efficiency of a given gun obviously occurs when "burnt" coincides with shot-ejection. The muzzle-energy

of the shot is then

$$\frac{\lambda C\Psi}{2(1+b)^2}\frac{W_1}{W_2}\left(\frac{dX}{d\phi}\right)_B^2. \tag{44}$$

The maximum value of W_1/W_2 is unity. Also the peak bore pressure is

$$P_{2m} = \frac{\mu(W_2 C\Psi\lambda)^{\frac{1}{2}}}{A(X_B - \nu)}$$

and the travel is

$$X_B = \frac{(X_B - X_0)}{\mu}\left(\frac{\lambda C\Psi}{W_2}\right)^{\frac{1}{2}}$$

so that the work done by P_{2m} acting through a distance X_B would be

$$\frac{\lambda C\Psi(X_B - X_0)}{(X_B - \nu)}. \tag{45}$$

From (44) and (45), the piezometric efficiency is

$$\text{P.E.} = \frac{(X_B - \nu)}{2(1+b)^2(X_B - X_0)}\left(\frac{dX}{d\phi}\right)_B^2. \tag{46}$$

For $b = \nu = 0$, this is a function of X_0 alone. The P.E. starts at 0.5 for $X_0 = 0$, rises to a maximum of about 0.6 near $X_0 = \frac{1}{4}$, and then falls to 0.5 again as X_0 tends to infinity. Increase of b increases the upper limit of the P.E. For $b = 0.5$, which is not likely to be exceeded in practice, the maximum P.E. is still less than 0.75. ν has very little influence on this limit, a value of $\nu = 0.2$ changing the piezometric efficiency by only 0.01.

Hence for H/L guns in which P_2/P_1 is always less than 0.555, the piezometric efficiency cannot exceed 0.8, which is less than can be obtained from orthodox guns. The analogous theory for orthodox guns gives a maximum piezometric efficiency of 0.88.

Although these equations can be applied as a guide when P_2/P_1 exceeds 0.555 for part or all of the solution, they become increasingly inaccurate as this ratio approaches unity; indeed, these solutions do not include the orthodox gun as a special case, in spite of having the same basic approximations. This arises from the parameter Ψ being assumed constant during the solution. An orthodox gun can, if one likes, be regarded as having a cordite chamber and a vanishingly small second chamber. The equations for such a system are included in this fundamental set, but as the variation of Ψ is important this method of solution fails.

If any H/L gun has a better piezometric efficiency than can be obtained from an orthodox gun, then the ratio P_2/P_1 must be greater than 0.555 for a large part of the motion. Although it cannot be said that this disproves the claim of a high piezometric efficiency, this claim is certainly made to seem unlikely. It is possible that the claim refers

to the conversion of some existing gun into a high-low pressure gun by using a special cartridge case. If the gun were relatively small-chambered the piezometric efficiency might well be raised in this change.

ACKNOWLEDGMENT.

I am indebted to Professor N. F. Mott, F.R.S., for his encouragement of this work, to Mrs. H. N. Wilkinson for computation of the solutions underlying Tables II–IV, and to the Chief Scientist, Ministry of Supply, for permission to publish this paper.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

NEW CRYSTALS FOR INFRARED SPECTROMETRY.

For the past two years scientists of the National Bureau of Standards have been engaged in a study of the thallium halide crystals to determine the feasibility of developing prisms of these substances for use in long-wavelength infrared spectrometry. While it has been known for some time that such materials possess optical properties of value for measurements in the infrared region, crystals of sufficient size for this purpose had never been produced.

During the recent war, mixed crystals of thallium bromide-iodide (generally referred to as KRS-5) were grown at Jena, Germany, and lenses were actually made from this material for use in field instruments. Early in 1946, under the direction of Dr. Francis Phelps, the Bureau began a program of growing crystals of the thallium halides, and a single mixed crystal of high purity was successfully grown. This crystal, which contained about 42 per cent thallium bromide and 58 per cent thallium iodide, was large enough for making a prism for use in an infrared spectrometer.

Crystals of the thallium halides are soft and semi-plastic, so that only slight pressures will set up considerable internal strains; hence, great precaution must be taken in annealing, cutting, and polishing. Edgar Robertson of the Bureau's Optical Shop succeeded in developing methods for grinding and polishing such crystals. He is now able to produce prism faces that are flat to within a few fringes of yellow monochromatic light. The prism which was made for use in the spectrometer has faces $1\frac{3}{4}$ by $2\frac{1}{2}$ in. Because of the high index of refraction, it was cut so that the refracting angle is 26 deg.

Measurements of the index of refraction of this prism have been made throughout the spectral region extending from the yellow mercury lines in the visible cut to 39.2 microns in the infrared, by L. W. Tilton and R. E. Stevens of the Optical Instruments Laboratory and E. K. Plyler of the Radiometry Laboratory. In the visible region, the value is approximately 2.6 while at 39.2 microns it is about 2.2. Changes in the index with temperature are large, so that constant temperature control is necessary in carrying out accurate spectroscopic work with this material.

Although prisms of other materials, such as potassium bromide, have been available for measurements to 24 microns, the new thallium bromide-iodide prism now allows observations to be made with a prism

* Communicated by the Director.

spectrometer all the way out to 40 microns. Making use of this prism in an infrared spectrometer, the Radiometry Laboratory is investigating the transmission of a great variety of materials from 24 to 40 microns.[1] It has been found that many compounds containing atoms of chlorine, bromine, and sulfur have bands in this region. Studies are also being made of the transmission of various solids to find materials having transmission characteristics that would make them suitable window materials for use in cells and in other applications in the 24- to 40-micron band. For example, it has been determined that thin layers of polystyrene and of polyethylene are very transparent out to wavelengths of 40 microns.

Data obtained in this investigation will be of material assistance in designing lens systems and in determining optimum prism angles for use in the different regions of the infrared spectrum. Other applications of measurements in this portion of the spectrum, such as chemical analysis by infrared methods, have also been worked out as a result of this work. Additional crystals of thallium bromide-iodide of the same high purity have been successfully produced in the Bureau laboratories.

PROPERTIES AND USE OF EYE-PROTECTIVE GLASSES.

In keeping with general industrial progress in this country, protective glasses and goggles have been developed and improved until today there is a glass or goggle available for adequate protection in every occupation and avocation. Recently, an investigation was made by Ralph Stair at the National Bureau of Standards covering the spectral-transmissive properties of about 200 glasses intended for use as sun glasses or for special industrial operations where injurious amounts of ultraviolet, luminous, or infrared radiant energy are present.[2] Extensive consideration was given to the elimination of glare, the distortion of colors of objects, the use of glasses for driving at night, the standardization of glasses for out-of-doors and industrial purposes, and the spectral-transmissive properties of glasses for use under various types and intensities of radiant energy.

Conservation of eyesight is one of the foremost problems that confront safety engineers in America today. The eyes must be protected not only from mechanical injury, but from exposure to various sources of radiant energy. The natural protective mechanism of the eye is sufficient to adapt it to ordinary amounts of radiant energy encountered about the home, office, shop, or other place of business or recreation.

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[1] For further technical details, see "Infrared Prism Spectrometry from 24 to 40 Microns," by Earle K. Plyler, *J. Research NBS*, Vol. 41, No. 2, August, 1948 (RP 1911).

[2] A comprehensive report of this work is being published as National Bureau of Standards Circular C471, "Spectral Transmissive Properties and Uses of Eye-Protective Glasses" by Ralph Stair.

However, in certain outdoor activities, for example, automobile driving and snow or water sports, and in industrial applications such as in steel mills, electric or gas welding, and around furnaces, glasses having low transmittancy to harmful radiant energy are required.

The principal reason for which most people wear dark glasses is to eliminate or reduce glare in connection with ordinary outdoor activities. Everyone, no doubt, has experienced the temporary blurring of vision, eye fatigue, or other unpleasant sensation caused by an excessive brightness—glare within the field of vision. The wearing of dark glasses simply reduces the brightness to a comfortable value such that the protective mechanism of the eye can assume complete control of the radiant energy reaching the retina. This result may be achieved through neutral, amethyst, red, amber, yellow, green, blue, or combination-color glasses so long as the optical density (shade number) is sufficient to reduce the luminous transmittance to the proper value for the light intensity encountered.

Glasses having sufficient opacity to give the eye reasonable protection from glare usually exhibit a considerable amount of selective absorbance and may appreciably alter the color of objects. The neutral-shade and smoke glasses have a roughly uniform absorbance throughout the visible spectrum and consequently cause the least distortion of color. On the other hand, since the maximum of visual response is in the yellow-green, for wear outdoors, glasses having a hue in the yellow-green or greenish-yellow portion of the visible spectrum are finding favor in aviation, automobile driving, and recreation. The slight distortion in object color appears to be of less importance than the gains obtained through elimination of radiant energy that serves no useful purpose.

Because of the serious risks involved, the use of dark glasses for relieving glare in night driving demands special attention. Most types of combinations of shaded glasses have been found to be unsafe as a means of protection against glare from automobile headlights. In general it is the belief that any advantage of reducing glare from automobile headlights by wearing dark glasses is more than counterbalanced by the extra hazard arising from the decreased visibility of objects. Tests by a number of observers indicate, however, some basis for claims of increased visibility and reduction of glare through the use of a yellow glass.

Present-day welding glasses having high opacity for the ultraviolet and infrared regions of the spectrum insure complete protection of the eyes when working with any source of radiant energy encountered in industry, provided the proper shade number for clear sight is employed. Since there are differences between individuals, the exact shade number for a particular operation must be chosen through trial by the operator himself for best results in his work.

In operations such as welding with coated rods, or in aluminum or

magnesium welding and cutting, producing high radiant flex at the wavelengths of the sodium lines, glasses containing didymium (and sometimes additional materials to absorb more completely the red end of the spectrum) have been found very useful.

Special cobalt-blue glasses have been used and demanded by operators of open-hearth furnaces and similar installations, in the particular shade with which the operator is familiar, because of the contrast in brightness that is obtained between the molten metal and the interior of the furnace. In the production of steel and cast iron by the Bessemer process, a blue-amber glass is employed by the operator to estimate certain color changes of the flame as the impurities are burned off. When each impurity (primarily silicon, magnesium, and carbon) burns as the result of an air blast through the molten metal, a distinctive color appears, on which the operator depends in determining the proper point at which to stop the "blow" and to pour the metal.

Ordinary glass, with its high sodium content, gives off an intense yellow flare when heated. Because of this bright light (at 589.3 millimicrons) the glass worker has difficulty in seeing, without special glasses, the glass to bend or shape it into the desired article. It has, therefore, become the practice of glass blowers to wear didymium glasses which have a high total luminous transmittance and at the same time high absorptance at 589.3 millimicrons.

When glasses having a high optical density are worn for protection of the eyes in industrial operations the elimination of harmful ultraviolet rays must be given first attention. The infrared rays are given second consideration because, their action being thermal, the worker is generally forewarned by a burning sensation. Finally the optical density, or shade number, determines the suitability of a glass for a particular operation.

Through accurate determination of the spectral transmittances and application of luminosity factors for a complete radiator (black body) at a color temperature of 2848° K., standards of optical density have been set up in the form of samples of welding glass having luminous transmittances near the minimum and maximum densities for the various shades.

As a result of the Bureau's investigation it has been proposed that sun glasses be grouped into three or four shades, *A*, *B*, *C*, and *D*, having luminous transmittances of 60, 35, 25, and about 10 per cent, respectively, values that correspond roughly with those for the industrial shades No. 1.5, 2.0, 2.5 and 3.0.

RESIN BONDING—A NEW DEVELOPMENT IN PAPERMAKING.

Through the use of a synthetic resin which imparts unusual strength to paper, vast amounts of wood which have been of little use in the

production of paper can now be added to the nation's critical supply of satisfactory pulp timber. This new technique in papermaking combines superior dimensional stability with high strength, when using the ordinary commercial wood pulps, and also makes it possible to produce suitable papers from relatively abundant wood species not now fully utilized. The development, growing out of a comprehensive research program at the National Bureau of Standards on offset printing papers, thus points to improved products and the conservation and extension of critical raw materials supplies. Furthermore, it does not involve either appreciable increase in costs or any important change in manufacturing methods.

Deciduous woods such as the maple, beech, birch, or poplar have until now been used only as "filler" in the manufacture of high grade printing paper. In 1946, for example, wood of this type accounted for only 16 per cent of the pulp consumed and in inventory. No matter how desirable their other characteristics may be, the deciduous woods do not produce the primary qualities of strength and resistance to surface pick, in the usual methods of processing. The development of strength through the use of the synthetic resin, melamine formaldehyde, will have the effect of materially increasing the use of the short-fibered pulps.

Paper is a felted sheeting of vegetable fibers, formed on a screen from a water suspension of the fibers. In conventional papermaking, the fibers are prepared for fabrication by mechanical beating in water. Beating causes the fibers to absorb water and form a gel-like film on their surfaces by a structural change called "hydration." This gel is the cement that bonds the fibers together to give paper of conventional manufacture its strength. Although this beating process has been necessary to provide sufficient fiber bonding for certain printing requirements, it also promotes some of the most troublesome behavior of paper in printing, namely, high expansion, excessive curling, slow oil absorption, and show-through of images.

The new technique consists essentially in substituting synthetic resin bonds between the fibers for the gel-like bonds formed by hydration. The resin bonding gives optimum strength with only a fraction of the beating required to develop comparable strength by beating alone, and produces a superior paper by elimination of the adverse effects of hydration. It is this feature of resin bonding that makes possible the satisfactory sheet strength from pulps of the deciduous woods that do not lend themselves to hydration. Resin-bonding thus opens up an entirely new reservoir of fibrous raw material.

Since paper was invented by the Chinese nearly 2000 years ago, there has been an almost unceasing search for fibrous raw materials. The use of wood, introduced some 75 years ago, brought a breathing spell after periods of near fiber famine. Under the present-day demand,

however, the available supply is running low. The magnitude of the fiber requirements for paper can be visualized roughly from the startling fact that all of the cotton grown in the world would not make one-quarter of the paper used in the United States.

In 1944, the Paper Laboratory of the National Bureau of Standards developed a high-wet-strength paper primarily for war maps, but made from conventional pulps. The unusual strength was acquired by substitution of resin bonding for the usual gel-like bonds occurring naturally during manufacture. The present development, involving experimental manufacture on a semicommercial scale, is essentially an extension of this work to the short-fibered pulps that possess every characteristic needed for good printing paper except the important one of strength. Widely different combinations of commercial wood pulps were investigated to determine the advantages of resin-bonding in printing papers. A series of papers was made from each combination with controlled variations in beating, with and without synthetic-resin bonding. In all instances, the resin-bonded papers were superior with respect to curling, oil absorption, folding endurance, resistance to surface pick, and expansivity. Several types of synthetic resins have been used, with melamine-formaldehyde resin giving the best results to date. Surprisingly small amounts of this resin are required, usually less than 3 per cent by weight.

Resin-bonding as a means of utilizing the deciduous woods is being further explored through the use of experimental pulps made specifically for investigations by the Forest Products Laboratory of the U. S. Forest Service. Included in these species are aspen, paper birch, and black gum. Pulps for this research have been prepared by various chemical processes and by mechanical grinding. Sulfite-cooked birch and sulfate-cooked aspen pulps have produced excellent printing papers with the aid of resin-bonding, whereas they can be used only in small amounts as fillers by conventional processing. These particular woods are among the most neglected in so far as paper making is concerned.

Some specific accomplishments with melamine resin-bonding are of interest. For normal commercial fiber combinations, it was possible to develop as much strength with 2 per cent of resin and no beating as with 9½ hr. of beating without resin. Far better strength and resistance to surface picking were obtained with 3 per cent of resin than could be achieved by hydration alone, even with the most drastic beating. Moreover, well-beaten papers were unsuitable for printing stock. In the use of deciduous-wood fibers such as birch sulfite and aspen sulfate, the addition of 1 to 3 per cent of melamine formaldehyde resin increased the resistance to surface picking and folding endurance more than ten times in some instances. Surface fibers must resist the pull necessary to transfer tacky ink from the rubber blanket to the paper without lifting or being themselves transferred to the blanket. A fiber

or bundle of fibers loosened by the pull of the ink not only leaves a blemish in the printed image on the sheet where the "picking" occurs, but it may cling to the blanket where it becomes moistened and repels ink so that it prints white spots on succeeding sheets.

All of the resin bonded papers showed low expansivity, essential, for example, in the printing of maps which may be run through the press as many as fifteen times. Expansivity was tested not only mechanically but in a series of printing tests using six colors.

An increase in the use of the short-fibered woods would have its most marked effect in the northeastern region of the United States. In this section, especially, the short-fibered woods have been increasing because past emphasis has always been on the use of the conifers, leaving behind the deciduous woods in logging operations. The ratio of conifers to other types has decreased to the point where the elimination of the short-fibered trees has actually become a problem in forest management.

With the United States using more paper than ever before in its history and the wood pile getting smaller, this new method should aid in making larger stocks available and provide another economic use for the non-coniferous trees. The Social Committee of the United Nations Economic and Social Council has warned that paper shortages are obstacles to freedom of the press. With no large new fiber sources available, the conservation and extension of our fiber resources becomes a matter of serious concern to all.

THE FRANKLIN INSTITUTE.

MUSEUM NOTES.

RUBBER EXHIBIT.

Science and technology know no geographical boundaries. The horizons are limited only by man's ingenuity and the materials with which he has to work. One of the most striking examples of what ingenious man can do to emulate and even surpass nature in the provision of useful things is exemplified in the rubber industry.

The Museum has been fortunate in securing the industrial cooperation of the Lee Rubber & Tire Company in equipping and decorating a room so that the comprehensive story of rubber may be told.

Beginning with a brief pictorial history of natural rubber and a superb wall map showing the distribution of its sources, the exhibits proceed to show the molecular structure of synthetic rubbers, and the significance of rubber in our modern world.

The people of the United States consume more than three-quarters of the world's supply of rubber, and the greater bulk of this goes to the manufacture of automobile tires. Since this application leaves relatively few families in the country unaffected, special attention is devoted to the manufacture of the component parts of the automobile tire.

An illustrated and illuminated flow chart shows the process of manufacture from crude rubber to finished tire, while a recorded talk assists the visitor to follow the process, reminding him that a tire is something more than a piece of molded rubber.

The Museum staff has always been concerned with the provision of dynamic exhibits which would enable the visitor to participate in the demonstration. In the case of this room devoted to rubber, opportunity has been taken to secure visitor participation by the provision of operable exhibits and demonstrations. For example, the simple push of a button will set in operation a device by which the rubber latex is coagulated and the usable base of commercial rubber is produced. By the exercise of a little strength, the visitor may learn the lesson of danger in a skidding tire and the safety furnished by a well treaded tire.

Still other demonstrations illustrate the properties of rubber. Everyone knows rubber's astonishing degree of passive resistance, how it will permit itself to be stretched, buffeted, pummelled, and mauled. Rubber's capacity to "take it" is due to its ability to absorb a blow and to return it. Therein lies most of its usefulness to man. But its other properties are not so well known. Its resistance to abrasion and its adhesive qualities when vulcanized are not so fully recognized, so that emphasis is placed upon these in operable demonstrations. The special properties of synthetic rubbers, such as the acid resistance and dielectric qualities, are similarly shown.

As admirable examples of the modern decorator's art, the rubber flooring and foam rubber "upholstery" of the seats further illustrate how the rubber goods manufacturer is taking advantage of the material which modern science is offering for his use.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from 9 A.M. until 5 P.M., Wednesdays and Thursdays from 2 P.M. until 10 P.M.

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BOOK REVIEWS.

FATTY ACIDS AND THEIR DERIVATIVES, by A. W. Ralston. 986 pages, 14.5 × 22 cm. New York, John Wiley & Sons, Inc., 1948. Price, $10.00.

Dr. Ralston, who is assistant director of the Chemical Research and Development Department of Armour and Co., has written in this volume an excellent comprehensive treatise on the chemistry of the fatty acids and their derivatives.

The first five chapters of his book describe the synthesis, occurrence in nature, and physical properties of those aliphatic acids containing six or more carbon atoms. The preparation of fatty acids from their natural sources, and processes for separating and purifying these acids are also described. The next six chapters discuss the historical background, preparation, physical and chemical properties of the major fatty acid derivatives. Esters, amides, nitriles, amines, quaternary ammonium salts, alcohols, ethers, mercaptans, sulfides, sulfonates, and other sulfur-containing compounds, acid anhydrides, acid chlorides, aldehydes, ketones, metallic soaps and other derivatives are discussed. One chapter describes compounds produced by modifying the long hydrocarbon chain. Another chapter is devoted to a consideration of long chain hydrocarbons; these may not ordinarily be considered as derivatives of the fatty acids. Commercial uses for each class of derivatives are briefly mentioned.

The rapidity with which this important field of chemistry is now developing is illustrated by the fact that the last chapter is an "Addendum" apparently written after the first eleven chapters and intended to bring them more nearly up-to-date.

The viewpoint of the book is academic and fundamental rather than industrial and tech-

nological. Naturally occurring glycerides are discussed only briefly. References to other books more adequately covering this subject are given. The very brief discussion of alkali metal soaps is inadequate in view of their great commercial importance and fundamental interest. References to work published during the past ten years on the polymorphic forms of soaps are not given. Phase studies of soaps are not mentioned and no reference made to the many publications on this subject.

The graphs, tables and figures are well done. However, much information now presented in sentences would be more easily understood and readily used if presented in tabular or graphic form.

The book is an authoritative and thorough summary of our present knowledge on the subjects discussed. Over 5000 references to original publications are given. In an effort to impart a good understanding of the field, the author has discussed, where he considered desirable, such allied subjects as some reactions of low molecular weight aliphatic acids, catalysis, theory of distillation, the reaction of carbon with fluorine, and the Stieglitz formulation of the Hofmann rearrangement.

Dr. Ralston received the 1946 Midwest Award of the American Chemical Society in recognition of his contributions to the chemistry of the fatty acid derivatives.

This book is highly recommended to those who may be interested in the subject. It should be widely used as a reference.

R. C. MERRILL.

ATOMIC ENERGY LEVELS, AS DERIVED FROM THE ANALYSES OF OPTICAL SPECTRA, Volume I, Section I, Circular 467 of the National Bureau of Standards, by Charlotte E. Moore. 75 pages, tables, 23 × 29 cm. Price, $0.50.

It is sometimes forgotten that quantum mechanics was the result of the knowledge of atomic spectra supplied by the spectroscopists of the nineteen twenties and thirties. The opportune publication in 1932 of Bacher and Goudsmit's "Atomic Energy States" showed clearly that, in a few years, the spectroscopists had provided the answer to most of the critical questions of atomic structure, but that they had only just begun the complete job of the analysis of the thousands of possible spectra. Since that time, a dwindling number of research workers have been attempting with some success to rectify the earlier errors, analyze more complicated spectra, and make the data of spectroscopy a reliable tool for the astronomers, the theoretical physicists and the users of spectro-chemical analysis.

One of the most active workers in the field has been the author of this book, Mrs. Sitterly, who in her incarnation as a spectroscopist is Miss Charlotte Moore, former assistant to Professor H. N. Russell at Princeton. When Professor Russell's retirement was imminent, Dr. Meggers of the Bureau of Standards was wise enough to recognize Mrs. Sitterly's unique value for their important work. No one could have been selected more competent to undertake the work which is now under way—the publication of a new version of Bacher and Goudsmit's "Atomic Energy States." That the time is opportune for such a revision was recognized by Dr. E. U. Condon when he became director of the Bureau of Standards after the war, and he has given the project every encouragement.

In May 1946, a meeting of the National Research Council Committee on Line Spectra discussed the project. That discussion and the answers to a questionnaire which was sent out afterwards, were used as a basis for deciding the details of the presentation. In the main, there was nearly complete agreement among the physicists consulted, but on a few points there was considerable disagreement. In particular, there was little argument over the question of the order of the spectra; Bacher and Goudsmit's alphabetical order, and all other suggested arrangements were rejected in favor of the more logical order of atomic number. The nomenclature for electron structures and for term types led to no disagreement, but on the notation to precede the term type there was much discussion. The difficulty comes from the complications introduced by different series limits and it has no completely logical and simple solution. The notation finally used in the section under review is a compromise which, like most compromises, will be disliked initially, and will later probably be used by everyone. I find it some-

what confusing that the unprimed letters such as $2p\ ^3P^\circ$ and $3s\ ^4P^\circ$ in F V refer to terms built on quite different limits.

During the preliminary discussions and since, I have disagreed wholeheartedly with one majority decision—the decision that all levels of a multiple term should be gathered together whether they are mixed in energy with other levels or not. This practice places more importance on the opinion of an investigator than on the one indubitable fact about a level—its numerical value. In the tables there is an excellent example of the distortion produced by this procedure. In the fluorine arc spectrum, the collection together of the components of $4d\ ^4D$ and $4d\ ^4F$ effectively conceals the really important fact that the seventeen levels of $2s^2\ 2p^4\ (^3P)4d$ are arranged in three very narrow groups whose separations are almost exactly the separation of the ^3P limit term. They are in fact a perfect example of J-j coupling, concealed by an arbitrary and quite unnecessary rearrangement.

Such criticism does not, however, detract from the job that Mrs. Sitterly has done. When it was remarked above that she is competent in the analysis of spectra, it was a definite understatement. Rather it should have been said that she is probably the only person there who is technically competent and at the same time has the temperament and training for such an arduous task. And it is a much more arduous task than might be imagined. The published material is spread through twenty or more journals and the unpublished material is in the papers of many more spectroscopists; it is presented in a different way and with a different notation by every individual; it is based on wave-lengths measured on all sorts of scales and with all sorts of inaccuracy; and it is full of errors of judgment and understanding. From such material, Mrs. Sitterly must sift out the nearest approach to a correct term table for each spectrum. She must, in fact, be an analyst of character as well as of spectra. I am sure that if I had to do the job myself, I would end up as a subject for a psychoanalyst.

The decision to produce the work in sections arranged by atomic number was a happy one, because it has meant that the first section on the elements up to fluorine has had as a background the quite outstandingly complete work of Professor B. Edlén, now of the University of Lund. Edlén's thesis which is a collection of data on the light elements and additions by him to most of them, constitutes the only homogeneous body of data on any group of spectra. Since the publication of that thesis, he and others in Professor Siegbahn's school in Sweden have examined so thoroughly the spectra of the light elements that the volume under review is largely the result of their work. They have been very generous with their great accumulation of unpublished data.

Even with the assistance of Professor Edlén's work, it is surprising that Mrs. Sitterly has been able to turn out such a finished piece of work in so short a time. Dr. Condon and Dr. Meggers should congratulate themselves on their perspicacity in recognizing the necessity for publishing this set of tables, and, equally, on recognizing that Mrs. Sitterly was the person to do it.

A. G. SHENSTONE.

THE INTERPRETATION OF SPECTRA, by William Mayo Venable. 200 pages, drawings, tables, 16 × 24 cm. New York, Reinhold Publishing Corp., 1948. Price, $6.00.

In this book, Mr. Venable has collected the available data on the emission spectra of hydrogen, deuterium, helium, lithium, sodium, and neon and attempted to interpret these and other spectra on the basis of a theory which he proposes. His theory is in direct contrast to the currently accepted theory of the emission of spectra as developed by Bohr and others which assumes, among other things, that spectral lines are the result of electronic transitions between different energy levels in an atom. Venable's theory postulates that "under excitation atoms may be separated into component sub-atoms," and that "these sub-atoms recombine with one another to produce the molecules cooperatively responsible for the observed spectral lines." In support of such a theory, he attempts to point out "intimate relationships between spectra emitted by supposedly entirely different sources."

Chapter one is a discussion of the history, development and assumptions of the presently accepted theory of the interpretation of spectra and that which Venable proposes. Chapters

2 to 7 are detailed discussions of mathematical relations between spectral lines. The work of Richardson, Merton, Dieke and Hopfield, Jeppesen and others on the hydrogen spectrum is critically discussed in considerable detail, sometimes without giving adequate references to the original literature

In chapters 8 to 14 attempts are made to begin development of a theory of spectra that accounts for the experimental facts without the assumptions of the quantum theory or without any assumption contrary to electromagnetic theory. The final chapter contains some highly theoretical speculations about the structure of atomic nuclei and the relationship of matter to the medium in which light is propagated. The author admits that these speculations are beyond the range of our present ability to test by experiment. The book contains predictions regarding the spectra of isotopes and mixtures which may be carried out as tests of Venable's theories.

This book will be completely understood only by those who have a good background in atomic and nuclear physics and spectroscopy.

R. C. MERRILL.

THERMODYNAMICS, by Lester C. Lichty. Second edition, 341 pages, illustrations, tables, charts, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1948. Price, $4.50.

Thermodynamics is often thought of as a very difficult, highly mathematical subject of little practical value. The present book is an attempt to disprove this. Many examples of applications are given and mathematical derivations are held to a minimum.

The title is misleading. Far from being a treatment of the general subject it is restricted to an introductory course in mechanical engineering thermodyamics. Heating of materials, change of state, fluid flow, and engines of various sorts are studied. Chemical reactions are very briefly treated in connection with combustion engines. No attempt is made to explain phenomena from a kinetic or statistical viewpoint.

The rigorous derivations of relationships between variables that loom so menacing in the early portions of most textbooks on thermodynamics are relegated to the appendix. However, entropy is introduced in the second chapter and used in connection with T-S diagrams, although the second law and reversible processes are not discussed until Chapter VII. Even here the explanation hardly seems adequate for what is always a difficult subject to beginners.

The chapters are of a convenient length, and contain many examples worked out. At the end of each chapter is a series of exercises of varying degrees of difficulty. The appendices contain many tables of useful information: properties of water, steam, ammonia, freon, mercury, carbon dioxide, energies and entropies of gases, and many useful charts on properties of gases and liquids.

NEWTON W. MCCREADY.

FUNDAMENTALS OF SOIL MECHANICS, by Donald W. Taylor. 700 pages, illustrations, 14 × 27 cm. New York, John Wiley & Sons, Inc., 1948. Price, $6.00.

Most structures rest on soil, and the role of soil as a foundation and construction material has always been one of high importance. However, soil mechanics was introduced to this country as a scientific discipline only in 1925. Its development since has been rapid.

The author, recognizing the extensive scope of the subject, has kept in mind primarily the graduate student when writing this book. Nevertheless, by omitting certain portions it may be used on the undergraduate level.

The theoretical material is described thoroughly and the emphasis of the book is on correlating the fundamental theories and their applications in the laboratory and the field.

Many aspects of soil mechanics are covered: the testing and classification, permeability, capillarity, seepage, settlement analysis, stability of slopes, retaining walls, pile foundations and many others.

The book is also well referenced and should prove of value to persons engaged in the field of foundation engineering.

H. N. MICHAEL.

ERUPTIVE ROCKS, by S. James Shand. Third edition, 488 pages, illustrations, 14 × 22 cm. New York, John Wiley & Sons, Inc., 1947. Price, $7.50.

As in the previous editions of this pioneering work, Professor Shand bases his concept of rock types on the chemistry of silicate systems, and thus continues his fight for the abolishment of the "jungle of rock names" which often cripples the perspective of the student.

The book is written for the advanced worker. Its third edition introduces much new material in nearly every chapter and is conveniently divided into two parts. A rough outline of the contents of the nineteen chapters of Part I would include discussions on the fixed constituents of eruptive rocks, the fugitive constituents, the temperature, pressure, and walls of magma on compatible and incompatible phases and on eruptive rock complexes. The discussion on linkage between eruptive rocks and ore deposits, which has been omitted in the wartime edition, is re-introduced and expanded and now covers Chapters X, XI, and XII of Part I. This part is concluded by a classification of eruptive rocks.

The four chapters of Part II dealing respectively with oversaturated, saturated, undersaturated non-feldspathoidal rocks, express the author's system of classification.

Numerous references are appended to each chapter.

H. N. MICHAEL.

PREPARATION AND CHARACTERISTICS OF SOLID LUMINISCENT MATERIALS. Symposium held at Cornell University, October 24–26, 1946. Sponsored by The Division of Electron Optics of The American Physical Society. 459 pages, illustrations, 15 × 22 cm. New York, John Wiley & Sons, Inc., 1948. Price, $5.00.

This monograph includes twenty-nine papers which were read at a conference on luminescence held in October, 1946, at Cornell University.

The eight introductory papers describe the general features of the phenomenon of luminescence and should prove informative to those who wish to acquaint themselves with this highly active field, and at the same time they should review, for the advanced, what has been accomplished in recent years. A brief note on the contents of these eight papers would include, besides the phenomenon of fluorescence itself, the most effective methods in preparation of solid luminescent substances called phosphors, the constitution and structure of phosphors, their storage and release of light, the infrared-sensitive phosphors, and the phenomena of excitation and emission found in these substances.

The remainder of the papers are contributions of original material, both experimental and theoretical, and are conveniently divided into three groups, dealing respectively with the factors affecting fluorescence characteristics, the storage of luminescence energy, and with miscellaneous aspects of fluorescence.

The first group included papers on the factors of temperature and composition, on effects of intensity variations of the exciting radiation, and some little-known aspects associated with the development of fluorescence in the glassy state.

In the second group, methods for the measurement of brightness decay of phosphorescent materials are described, and there are three papers which concern themselves with the measurement and interpretation of stored energy. The last paper of this group deals with the stimulation of zinc sulfide phosphors.

The third group contains eight papers. The topics covered here are diverse. Effects of ultraviolet and X-rays, absorption measurements, relation between molecular structure and ability to fluoresce, and an unusual study of the motions of electrons in silver-halide crystals in an electric field, are some of the phenomena discussed, and indicate the diversity of the subjects in this group.

The concluding twenty-five pages of the text are devoted to the topics which had arisen during the extemporaneous debate on the last day of the conference. They express the trend of thought in regard to experimental and theoretical research which may be undertaken in order to gain a more quantitative understanding of luminescence.

H. N. MICHAEL.

MINERAL RESOURCES OF THE UNITED STATES, by the Staffs of the Bureau of Mines and Geological Survey. 212 pages, maps, charts, and tables, 21 × 28 cm. Washington, D. C., Public Affairs Press, 1948. Price, $5.00.

This publication is the result of five years of intensive research by some fifty-three staff members of the Bureau of Mines and the Geological Survey of the U. S. Department of the Interior. It presents a quantitative appraisal of the mineral-resource position of the United States, and is the most comprehensive appraisal yet attempted. There are thirty-nine individual commodity chapters which estimate the reserves for the more important metals and minerals used in American industry. These commodity chapters are prefaced by several introductory ones which discuss the economic and technological factors from a national viewpoint as applied to the mineral industry as a whole. There is also an historical review and an interpretive summary of the reserve data given in the individual commodity chapters.

The report reveals that those minerals basic to the maintenance of our present kind of industrial society are not wanting, contrary to recent "scarehead" reports. All in all, our mineral outlook is favorable but, as Secretary of the Interior Krug puts it, "it is obvious that a dynamic program of research and exploration must be pursued if new sources are to be developed to supply future needs."

A simple enumeration of the commodities covered by this report will best indicate its comprehensiveness: antimony; arsenic; asbestos; bauxite; bismuth; cadmium; chromite; coal; cobalt; copper; industrial diamonds; fluorspar; gold; graphite; helium; iron ore; lead; magnesium raw materials; manganese; mercury; strategic mica; molybdenum; natural gas; nickel; nitrates; petroleum; phosphate rock; platinum metals; potash; quartz crystal; salt; silver; sulfur; tantalum; tin; titanium; tungsten; vanadium; zinc.

The numerous tables, charts, and maps indicating the trends of production, distribution of deposits, probable reserves, are among the most valuable features of this publication.

Although it is stated that the purpose of the report is to make the above-described information available to the legislative and executive branches of the Federal and State Governments, the very nature of this publication should make it a "must" as a reference in all college geography and geology departments and to other public schools in general.

H. N. MICHAEL.

CHYMIA, ANNUAL STUDIES IN THE HISTORY OF CHEMISTRY, Volume I. 190 pages, plates, 15 × 23 cm. Philadelphia, University of Pennsylvania Press, 1948. Price, $3.50.

Published under the auspices of the Edgar F. Smith Memorial Collection at the University of Pennsylvania, this new annual promises to become an important medium for the distribution of writings on the history of chemistry. With a strong list of consulting editors, as well as an editorial board headed by Tenney L. Davis, the project carries an authoritativeness which augurs well.

The lead article is by the late C. A. Browne on Frederick Accum, celebrated London chemist of the early nineteenth century. As the result of an earlier article on Accum, Dr. Browne had been able to get in touch with a great-grandson of Accum who supplied information on many previously obscure points. It is this new information which Dr. Browne has discussed in his present article.

Then follows a tribute to Dr. Browne, who had taken an active role in initiating *Chymia* and who served as its Editor-in-Chief until his death early in 1947. The tribute is supplemented by a bibliography of his historical writings, which number 148 published items and 17 unpublished manuscripts deposited in the E. F. Smith Memorial Library.

One of the more significant papers in relating the discovery of new facts is that by Sidney M. Edelstein entitled "Priestley Settles the Water Controversy." A recently discovered letter from Priestley to Sir Joseph Banks is quoted as revealing Priestley's belief that Watt had "the idea of water consisting of pure air and phlogiston . . . before I knew him." Mr. Edelstein then reviews the evidence in the controversy and shows that the leading proponents of the two main claimants, Watt and Cavendish, were agreed that Priestley could settle the matter. Thus this letter becomes a most significant piece of evidence in support of Watt's claim.

Among the other papers are "The Early Use of Potassium Chlorate in Pyrotechny" by T. L. Davis; "Factors Which Led Mendeleev to the Periodic Law" by H. M. Leicester; "The Early Chemical and Pharmaceutical History of Calomel" by G. Urdong; "Pierre Louis Dulong, His Life and Work" by P. Lemoy and R. E. Oesper.

Of special interest to historians of chemistry should be the paper on "Thomas Thomson, Pioneer Historian of Chemistry" by H. S. Klickstein. This is an interesting review both of the man's life and of his principal writings, concluding with a bibliography of his chief publications on the history of chemistry.

In all there are thirteen papers, most of which are accompanied by suitable illustrations, principally portraits. In variety of material and method of presentation this first volume of *Chymia* has set a high standard.

G. E. PETTENGILL.

CHRISTIAN HUYGENS AND THE DEVELOPMENT OF SCIENCE IN THE SEVENTEENTH CENTURY, by A. E. Bell. 220 pages, illustrations, 14 × 21 cm. New York, Longmans, Green & Co., 1947. Price, $4.50.

Among the great scientists Christian Huygens stands a somewhat neglected figure. Although his writings have been collected in a magnificent set of more than twenty volumes by the Société Hollandaise des Sciences, not much attention has been paid to an adequate evaluation of his work. This volume by Dr. Bell is an attempt to rectify the situation.

The book is divided into two main parts, the first consisting of a narrative account of Huygens's life. This treats of the personal details of his life as well as fitting into a chronological picture his principal writings.

The second part is devoted to a more particular analysis of Huygens's scientific work. The first chapter considers the state of science in the first half of the seventeenth century. Subsequent chapters consider various phases of Huygens's studies—collisions between elastic bodies, centrifugal force, statics, cause of gravity, optical studies, the wave theory of light Saturn and Cosmotheoros. Four chapters are devoted to the important treatise on the pendulum clock, the "Horologium Oscillatorium."

Many pertinent illustrations and diagrams are included. A section comprising biographical notes on some of the persons mentioned and a short bibliography are additional useful features.

Although Dr. Bell himself lays no claim to having written more than a beginning account in English, it is a thoughtful and well considered delineation of some of the principal aspects of Huygens's career and works.

G. E. PETTENGILL.

PHYSICS OF METALS AND ALLOYS, by Walter Boas. 193 pages, illustrations, 16 × 25 cm. New York, John Wiley & Sons, Inc. Price, $3.50.

Physical theory has been applied extensively to metallurgy during the past twenty-five years. Crystal structures of metals and alloys and the arrangement of crystals in a polycrystalline aggregate have been determined through the application of X-ray diffraction.

This book, introductory in nature, deals with the development of the physics of metals from a definite point of view. Its main principle could be expressed in the statement that "the properties and the arrangement of the crystals determine the properties of polycrystalline aggregates."

Simple crystallography and some methods of X-ray diffraction are taken up in the first part of the book. This forms a basis for the understanding of the remainder of the text which is concerned with the properties and deformation of metals and with phase-changes in alloys. The physical properties are explained in terms of the properties of the atoms. The concluding part of the book describes chemical and phase-changes produced by alloying and heat treatment. General rules derived from extensive studies of these changes, of their mechanism and causes, are given.

The general, introductory nature of the book should prove of value to metallurgists and chemists by forming a solid basis for further studies.

H. N. MICHAEL.

PUBLICATIONS RECEIVED.

An Introduction to Color, by Ralph M. Evans. 340 pages, 19 × 25 cm., plates and drawings. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1948. Price, $6.00.

Industrial Electronics Reference Book, by Electronics Engineers of the Westinghouse Electric Corp. 680 pages, 23 × 30 cm., tables, drawings and illustrations. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1948. Price, $7.50.

Inorganic Process Industries, by Kenneth A. Kobe. 371 pages, 16 × 24 cm., tables, drawings and illustrations. New York, The Macmillan Co., 1948. Price, $6.00.

College Physics, by Henry A. Perkins. Third edition, 786 pages, 16 × 23 cm., tables, drawings and illustrations. New York, Prentice-Hall, Inc., 1948. Price, $6.65.

Essentials of Physics, by Carl F. Eyring. 422 pages, 14 × 21 cm., drawings, illustrations, and plates. New York, Prentice-Hall, Inc., 1948. Price, $5.00.

Sequence in Layered Rocks, by Robert R. Shrock. 507 pages, 16 × 23 cm., illustrations and drawings. New York, McGraw-Hill Book Co., 1948. Price, $7.50.

The Function and Design of Army Searchlights, by E. W. Chivers and D. E. H. Jones. 164 pages, 15 × 24 cm., tables, drawings and illustrations. London, The Illuminating Engineering Society, 1948. Price, 18/6d. (paper).

Science, Servant of Man, by I. Bernard Cohen. 362 pages, 14 × 21 cm., plates and drawings. Mass., Little, Brown & Co., 1948. Price, $4.00.

Mathematics Our Great Heritage, by William L. Schaaf. 291 pages, 14 × 21 cm. New York, Harper & Brothers, 1948. Price, $3.50.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Inhibitors for Ribonucleinase.—CHARLES A. ZITTLE. In preparing the nucleic acids from biological sources it is desirable to be able to inhibit the enzymes which act on the nucleic acids so that maximum yields of nucleic acid in unaltered state can be obtained. McCarty and Avery (1), for example, have obtained a five-fold increase in the yield of desoxyribonucleic acid (DNA) from pneumococci by inhibiting the DNA-ase with citrate.

For the isolation of ribonucleic acid (RNA) it would be desirable to inhibit the specific enzyme ribonucleinase (RNA-ase) which cannot be inactivated by heat treatment (2). Copper in a concentration of 0.006 *M* inhibited RNA-ase 80 per cent (3) but tissue substances (such as those containing sulfhydryl, for example) probably would counteract this inhibition and the copper would have to be removed after extraction of the nucleic acid since it is bound by nucleic acid (3). Zinc is somewhat less inhibitory than copper (3).

In the present studies formaldehyde, ninhydrin, phenylisocyanate, as well as NaCl in high concentration, have been found to be inhibitory to RNA-ase. None is highly specific or active in high dilution but some may justify further study.

EXPERIMENTAL.

Crystalline RNA-ase was used and its activity with and without inhibitors present was determined manometrically at pH 7.5 (4).

Since RNA-ase is a basic protein, having an isoelectric point of 8.0 (2), the influence of acidic substances on it was investigated. In these experiments about 30 micrograms of RNA-ase were introduced into the test system containing the acidic substance in a final concentration of 0.004 *M*. None of the following had any effect: picric, sulfanilic, salicylic and phthalic acids.

In addition, reagents combining with amino groups were investigated because of the basic nature of RNA-ase. These were inhibitory. Shown in Fig. 1, curve B, is the effect of formaldehyde on RNA-ase. In these experiments the formaldehyde was in contact with the enzyme before the enzyme was added to the substrate. Ninhydrin tested in the same way gave an identical inhibition curve.

Phenylisocyanate completely destroyed the activity of RNA-ase under the following conditions: 0.01 cc. of phenylisocyanate was stirred into 20 cc. of 0.025 *M* $NaHCO_3$ containing about 2.5 mg. of the enzyme. The precipitate of diphenylurea was removed by centrifuging and the supernatant fluid assayed for RNA-ase. Samples containing as much as the equivalent of 70 micrograms of RNA-ase had no activity.

The inhibitory effect of NaCl on RNA-ase was investigated by the procedure used for the acidic substances with the results shown in curve A, Fig. 1.

DISCUSSION.

The reagents formaldehyde, ninhydrin and phenylisocyanate react with amino groups, the first two compounds with other groups as well, and they probably inhibit RNA-ase in consequence of this ability to react with amino groups. Thus it can be concluded that amino groups are essential for the activity of RNA-ase as is the case with alkaline phosphatase (5). Further study would be required to determine

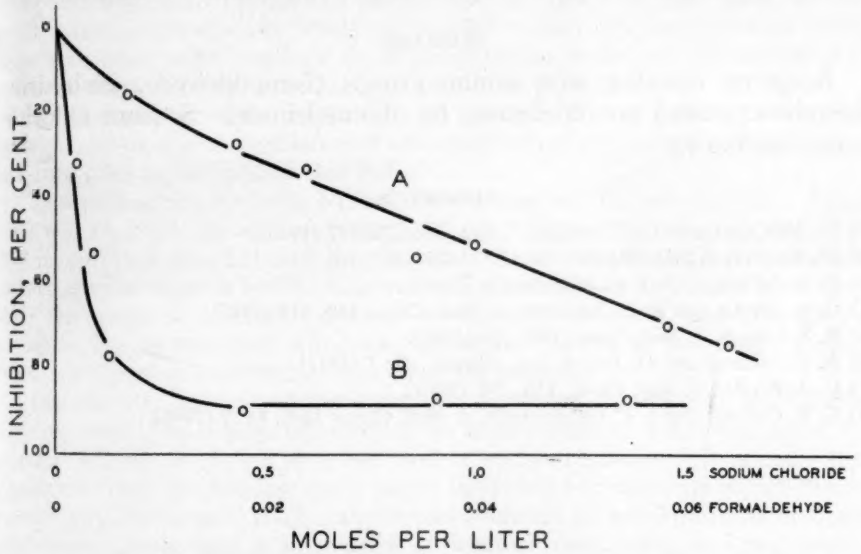

FIG. 1. Effect of formaldehyde and sodium chloride on the hydrolysis of ribonucleic acid by ribonucleinase.

Sodium chloride: Curve A, concentration shown by upper legend.
Formaldehyde: Curve B, concentration shown by lower legend.

whether any of these reagents would be useful for inhibiting tissue RNA-ase when RNA is being prepared. Unfortunately the reagents are only relatively specific and they would react with other tissue proteins as well so that the amount of the reagent required might be difficult to determine. The possibility of interaction with nucleic acid would have to be considered also. If changes in the nucleic acid did occur the possibility remains that the changes might be reversible.

Investigations of the effect of NaCl on RNA-ase were prompted by the observations of Mirsky and Ris (6) on chromosomes which were relatively stable in 2 *M* NaCl but unstable in 0.14 *M* NaCl in which RNA appeared in the supernatant fluid. The inhibitory effect of NaCl on purified RNA-ase, shown in Fig. 1, suggests that this enzyme may

be involved in the instability of chromosomes. The less specific phosphodiesterase, prepared from calf intestinal mucosa (7), which acts on RNA, may be involved also for 0.25 *M* NaCl exerts a 30 per cent inhibition of this enzyme. In view of these effects of NaCl, extraction of RNA with concentrated salt solutions might be advantageous, for NaCl is more readily eliminated than the more inhibitory reagents discussed above. Carter and Greenstein (8) have reported a stimulating effect of salts (0.1 *M* and less) on RNA-ase but dilute solutions of RNA (1.0 mg. per 1.0 cc.) were necessary. In our experiments the concentration of RNA was 43 mg. per 1.0 cc. and in addition 0.03 *M* $NaHCO_3$ was present initially so the effect reported by these authors would not be observed.

SUMMARY.

Reagents reacting with amino groups (formaldehyde, ninhydrin, phenylisocyanate) are inhibitory to ribonucleinase. Sodium chloride is also inhibitory.

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CURRENT TOPICS.

Weather Towers Near Completion at Brookhaven Laboratory.—Two meteorological towers for weather observations in connection with nuclear research are nearing completion at Brookhaven National Laboratory. The taller tower, to be 420 ft. high, is comparable in height to a 35- or 40-story building, and will be the tallest structure on Long Island, laboratory officials believe. The second tower, 160 ft. high, is already complete, and the taller tower was complete with instruments the latter part of July. At five levels on the small tower, and at eight levels on the tall tower, will be platforms where observers may take readings from instruments, including anemometers to measure wind velocity and direction, and thermometers.

A main purpose of the meteorological towers will be to furnish information on wind currents in connection with safe operation of the nuclear reactor (chain-reacting pile) to be finished this Fall.

The nuclear reactor being built at Brookhaven will be cooled by air. Large fans will conduct the air away from the pile, through an air duct, and up a 300-ft. air-stack on a hill near the reactor. In the air will be minute quantities of radioactive argon, a well-known inert gas, which will be dissipated harmlessly into the upper air. Study of wind velocity and direction, and atmospheric pressure, during operation will permit control of the pile so that air emanating from the stack will not settle on or near the ground.

Instruments on the weather tower and elsewhere on and near the Laboratory site will give precise information on wind currents, and operation of the reactor will be controlled at a low level or stopped entirely if it appears that radiation from the cooling stack under unfavorable conditions would not be completely harmless. With complete information on wind currents at upper and lower levels, and a knowledge of weather conditions on Long Island, scientists are thus assured that operation of the reactor will be harmless to neighboring communities and plant and marine life in the vicinity.

Another feature of the tall weather tower will be a smoke stack which will carry only smoke created for the purpose of studying wind and weather. This is a 20-in. steel pipe running the height of the stack, and it will dissipate smoke produced by an army surplus M-1 smoke generator, similar to those used by naval vessels and beachhead troops in laying down smoke screens to conceal an operation. It produces a harmless oil fog smoke, 10,000 cu. ft. of smoke per minute, and at some time during tests it may create a small cloud over or around the Laboratory, which, under ideal weather conditions, might be visible for several miles.

Weather instruments on the towers will be mounted on beams which can be swung out away from the towers, and then pulled in for observations. In addition, the observations will be recorded electrically on an instrument panel in a building 900 ft. away from the towers. The building has to be this far away from the towers so that eddies created by winds passing over the building will not disturb observations made by instruments on the towers. Two

electrified cables between the towers will also carry instruments to record temperatures and wind differences between them.

The meteorology group at the Laboratory will afford facilities for study and research by scientists of the permanent staff and by others who come on leave from their regular jobs elsewhere. The Weather Bureau, in addition to research, will be orienting and training U. S. Weather Bureau personnel, who will be assigned to similar work elsewhere.

Public Lands in Colorado and Utah Reserved for Uranium Drilling.—The U. S. Department of the Interior has advised the U. S. Atomic Energy Commission that in accordance with a request from the Commission it has approved an order (Public Land Order 494) withdrawing from entry and reserving for use of the AEC approximately 115 square miles of public land in Southwestern Colorado and Southeastern Utah.

The U. S. Department of Interior, at the request of the AEC, recently approved an order (Public Land Order 459) withdrawing from entry certain lands in San Miguel and Montrose counties in Colorado. The present order (Public Land Order 494) covers certain portions of lands located in Grand County, Utah, lying in Township 24S-R25E., T24S-R26E., T25S-R25E., T25S-R26E., and certain portions of lands located in Mesa County, Colorado, lying in T49N-R17W., T49N-R18W., T50N-R17W., T50N-R18W., T50N-R19W., T50N-R20W., T51N-R18W., T51N-R19W., T51N-R20W., T15S-R104W.; also included in the order are portions of lands in San Miguel County, Colorado, lying in T43N-R18W., T43N-R19W., T43N-R20W., T44N-R18W., T44N-R19W.

During this summer the Commission, with the cooperation of the U. S. Geological Survey, intends to make a comprehensive study of these areas and to test by diamond drilling for uranium bearing ores. Lands found to contain no uranium will be released from the withdrawal orders and will again be open for entry. It is expected that in furtherance of AEC policy the lands found to contain uranium will become available for development and mining by private interests under arrangement with the Government. No further withdrawals are contemplated at this time until the lands now withdrawn have been thoroughly examined and arrangements have been made for their development or relinquishment.

Wood Research Laboratory Facilities Enlarged.—Growing recognition of the value of research to the lumber industry has resulted in an expansion of plant and facilities of the Timber Engineering Company wood research laboratory.

Recent completion of a 60 by 60 ft. one-story addition to the laboratory makes possible additional services for the manufacturers and users of lumber and wood products. The laboratory, established in 1943, is engaged in product development and research on the chemical, physical, and mechanical properties of wood.

To expand markets for lumber, Timber Engineering Company pioneered to gain recognition of wood as an engineering material and developed the Teco connector system of wood construction. Facilities at the lab include equipment developed especially for testing full scale 50-ft. trusses—the only equipment of its kind in the country.

To improve the mechanical wear of railway ties is a new project that is jointly sponsored by associations of lumber manufacturers and the Association of American Railroads.

Another far reaching study just started is aimed at developing an economical and practical means of decreasing the shrinking and swelling of construction lumber and other wood products.

Finding economic uses for low-grade and waste hardwoods is a major project under way at the laboratory. Development of a hardwood pulping process has formed the basis for the production of many valuable new products out of material formerly considered unusable.

Users of wood office furniture will benefit from such Teco developments as burn and stain-proof desk tops and non-marring desk legs.

The new laboratory building itself is a tribute to the strides in wood engineering resulting from industry research. It is built with glued laminated timber girders (9½ in. by 24½ in. by 20 ft) which will support a second floor when further expansion is desired. The girders are built up of 15 laminations of 1⅝-in. material and were produced by Rilco Laminated Products, Inc., Wilkes-Barre, Pennsylvania.

New THER-MONIC Core Baking Tunnel.—The new THER-MONIC Electronic Core Baking Tunnel was exhibited in operation at the 52nd American Foundrymen's Association Congress and Show in Philadelphia, Pennsylvania. This unit represents the culmination of two years of intensive research and development by the Induction Heating Corporation, Brooklyn, New York, since they first presented Electronic Core Baking in 1946.

This model, with an average baking cycle of only a few minutes, has a capacity of 650 lb. of cores per hour and will produce a ton of baked cores at a power cost of only 92¢.

Production experience, during the last two years, in foundries throughout the United States has revealed many outstanding advantages for this new method of core baking. Electronic heating times are in the order of 20 seconds to a few minutes, whereas the minimum baking cycle in combustion ovens usually runs from 1 to 4 hr. Now cores can be baked as they are needed in the pouring room and changes in molding schedules can be effected without any thought as to what cores are in stock. The necessity for advanced scheduling of core-room activity is removed. This rapid baking cycle also prevents core sagging during the baking operation.

Green cores may be loaded, in the core-room, directly onto the THER-MONIC tunnel conveyor, eliminating all the racking and much of the handling of the cores in the green state.

After the baking cycle, the core plate emerging from the tunnel may go directly onto the inspection table. There is no cooling period involved and the cores are ready for immediate inspection and use. The conventional method of loading and unloading large storage racks is entirely avoided. With conventional methods of core binders and baking, between 30 per cent and 40 per cent of the cores never find service in the foundry. Compared with this, by the use of THER-MONIC Electronic Core Baking and synthetic resin binders, these losses are cut to less than 10 per cent.

The THER-MONIC method makes it possible readily to adjust and control the green strength, hot strength, hardness, collapsibility, and other characteristics of the cores. This ready control makes it easy to overcome the problems of hot tearing, burning in, and poor finish of the casting. Shake-out is so complete that core residue may be removed without mechanical assistance.

Measure Honey in "Bee-Years".—The bee is a busy worker but not a big one. Bee specialists of the U. S. Department of Agriculture say the average bee collects several times her weight in honey in a season, but this is only about a quarter of an ounce on the average. So, if a bee could live that long it would take her about 64 years to make one pound of honey. But while the bee is making her quarter of an ounce of honey she is making untold wealth in the form of apples, melons, clover seed, and many other fruits and seeds through her pollinating activities.

United Nations Scientific Conference on the Conservation and Utilization of Resources (UNSCCUR).—United Nations Scientific Conference on the Conservation and Utilization of Resources will be held in the United States in May-June 1949 under the authority of the Economic and Social Council of the United Nations.

This Conference represents a new approach to one of the objectives of the United Nations, the promotion of economic development and higher standards of living throughout the world, by a free exchange of ideas and experience on the conservation and utilization of resources.

In its plenary meetings, comprising approximately half of the programme, the Conference will examine the contribution of improved techniques to the alleviation of shortages of mineral resources, fuel and energy, and food and forest products. A series of plenary meetings will be devoted to questions of particular importance to underdeveloped countries.

Specific problems and techniques will be placed on the agenda of specialized section meetings which form the other half of the programme. In these meetings, specialists will discuss Conference Papers on subjects such as forests, water, fisheries and wildlife, fuel and energy, power, mineral resources; and the interrelated group of subjects included under soils, crops, grazing and livestock resources.

The Conference will be scientific rather than policy-making. Technical developments will be selected for discussion according to the importance of their practical contribution, actual and potential, to economic development and will be treated so as to interest the economist as well as scientist, administrator and engineer.

Conference Papers submitted by experts as well as summary records of discussions will be published after the Conference, and it is expected that they will be a continuing and important contribution of the United Nations to better conservation and utilization of resources.